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NAVAL POSTGRADUATE SCHOOL

RESEARCH

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TIME CRITICAL STRIKE: NPS RESEARCH SUPPORTS THIS FUTURE NAVAL CAPABILITY

In 1998 the Future Naval Capabilities process was instituted to raise the Science and Technology investment focus from individual technology goals to the achievement of future capabilities for the Naval Forces of the future. Input to the Future Naval Capabilities came from the CINC's Command Capability Issues (CCIs) and from OPNAV/HQMC capabilities needs submission.

Time Critical Strike is one of the twelve Future Naval Capabilities. Warfighters need the ability to strike tactical, operational and strategic targets at the right moment in the right battle. The warfighter must strike targets in compressed vulnerability windows in all joint operations, in any environment, under all conditions. Because battles may be decided in minutes, the need to strike with unprecedented accuracy, flexibility and speed is more critical than ever before.

Faculty at the Naval Postgraduate School are actively engaged in cutting edge research with a focus on Navy and DoD problems. The primary purpose for research at a graduate level institution is to provide relevant student thesis topics, maintain faculty expertise, and maintain the upper division course content. Research at NPS has an even broader reach. Faculty and students can work on problems that can directly affect a "critical need" or in this case, a Future Naval Capability. Students with their unique knowledge of operations working with their faculty advisors provide a very unique capability for addressing warfighting problems.

Provided below is an overview of NPS faculty and student research in support of Time Critical Strike.

Self-Synchronization Examined as a Critical Aspect of Time Critical Strike

The Naval Postgraduate School Adaptive Architectures for Command and Control (A2C2) research team (**Assistant Professor Susan Hocevar, Research Assistant Professor Susan Hutchins, Associate Professor William Kemple, Research Professor David Kleinmann, Research Assistant Professor Gary Porter, Emeritus Professor Michael Sovereign**), in partnership with OPNAV (N6C), SAIC, and Aptima (an A2C2 partner), recently completed Concept Development Game 1 (CDG 1) in support of OPNAV N6's Advanced Command and Control (AC2) Study. The objective of the AC2 study is to investigate the nature of C2 as the U.S. Navy evolves toward a network-centric concept of future maritime operations. The focus of CDG 1 was self-synchronization as it applies to Time-Critical Strike (TCS) and Theater Air-Missile Defense.

The partnership between NPS, OPNAV, SAIC, and Aptima was formed subsequent to a three-day Advanced C2 Roundtable, held in September, at NPS. During this roundtable an innovative concept development and experiment process was formulated, composed of integrated activities, tools, and methods which capitalize on the A2C2 team's capabilities.

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At the roundtable, N6C delineated a series of detailed short-term objectives and a number of long-term planning objectives linked to overall study topics and desired outputs described by the N6C "Waterfall Diagram" (Figure 1).

A "hybrid" approach is being used to examine both qualitative and quantitative issues identified by N6C as requiring investigation. A multi-disciplinary approach, including seminar games, models and simulations, interviews, surveys, and other knowledge capture methods will match these methodologies to the requirements of formal experimentation. Last, the team was tasked to respond to real world problems and operator-driven requirements and integrate these into the experiment process. To satisfy these diverse challenges, the A2C2 team proposed the "Focus Process" (Figure 2), which uses seminar-style concept development games as data-generating activities from which testable hypotheses can be derived.

TCS operations are conducted against targets that pose a clear and present danger to friendly forces or are highly lucrative, fleeting targets of opportunity that require an immediate response. Network-centric operations provide the basic foundation required for a successful TCS mission to occur: rapid information

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(Above) The AC2 Planning Roundtable consisted of three days of in-depth, team discussion at the Naval Postgraduate School.

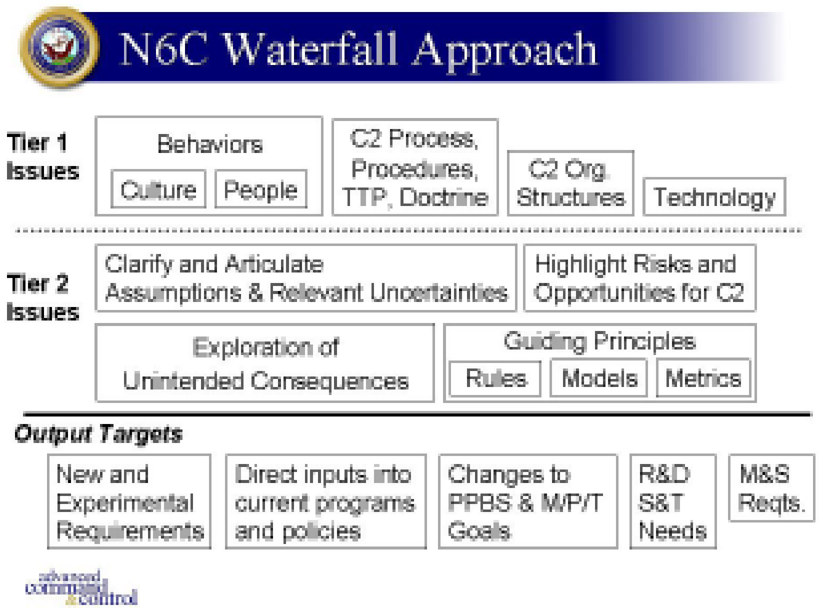
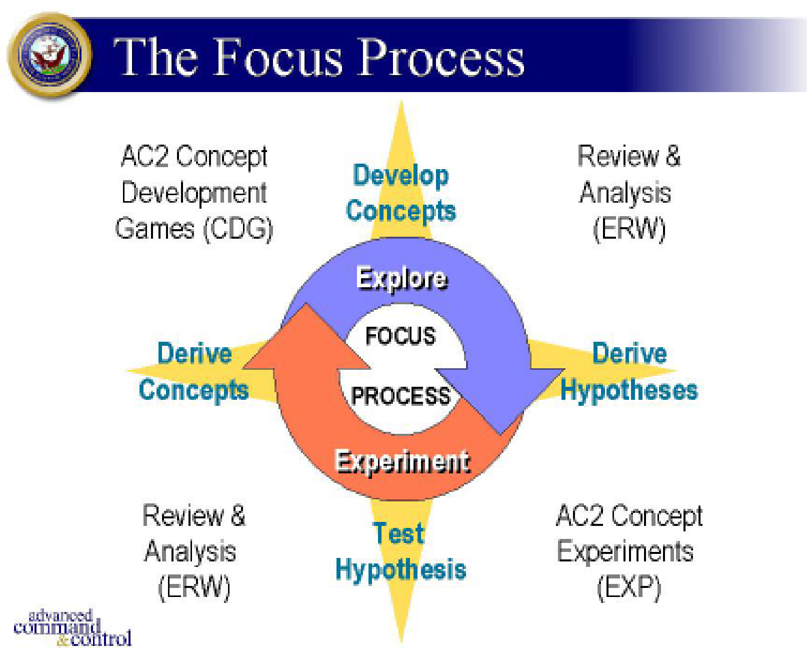


Figure 1. (Left) Waterfall Design.

Figure 2. (Below) Focus Process Diagram.



TIME CRITICAL STRIKE, *continued from page 2*

sharing, more timely development of situation awareness, more efficient use of available resources — all lending support to achieving faster decision cycles. In addition to new tactics and technology, modified human decisionmaking processes are required to enable Joint military forces to operate in a time span that is shorter than an adversary's.

Self-synchronization is viewed as an essential process within military organizations to increase speed of command and speed the execution of the mission. Time-critical targets, by definition, have compressed vulnerability windows and time-dependent values. These timing constraints, inherent in TCS, place additional emphasis on coordination and synchronization of these strikes with other theater operations. TCS needs to be supported by a C2 system capable of rapidly synchronizing across the battlespace. Technology contributes the essential foundation for rapid information sharing, however, the human decisionmaking process must also be accelerated by enabling self-synchronization.

The team determined that the organization of CDG-1 would follow a format to facilitate specific forms of data collection and insight generation (Figure 3). Blue and Red teams were asked to generate ideas and concepts while competing in a scenario chosen for its utility in experimentation. The two Blue teams were provided a common organizational form, order of battle, commander's intent, and rules of engagement and were tasked to solve specific, focused military problems in two vignette-driven moves. After each vignette-driven move, data was collected and a briefing prepared for presentation during a guided plenary session. All teams were composed of a generational mix of officers with recent fleet experience. The Blue teams focused on the positive attributes of their organization and the Red team focused on the negatives. A final integration move culminated the activity and afforded the opportunity to expand upon insights and add descriptive depth to concepts in a cooperative environment, in contrast to the competition of the previous moves.

CDG-1 was used as a data-gathering activity to derive hypotheses about how self-synchronization will occur within the organization. The goal was to identify aspects of advanced C2 for later testing in a human-in-the-loop experiment scheduled for 26 February–9 March 2001. NPS's Distributed Dynamic Decisionmaking (DDD III) simulation tool will be used to drive the experimental scenario and collect data for subsequent analysis. Two organizational structures and two levels of "enablers" of self-synchronization will be tested when participants respond to scenarios that include TCS missions. The objective of the experiment is to determine the conditions under which self-synchronization can most effectively be achieved.

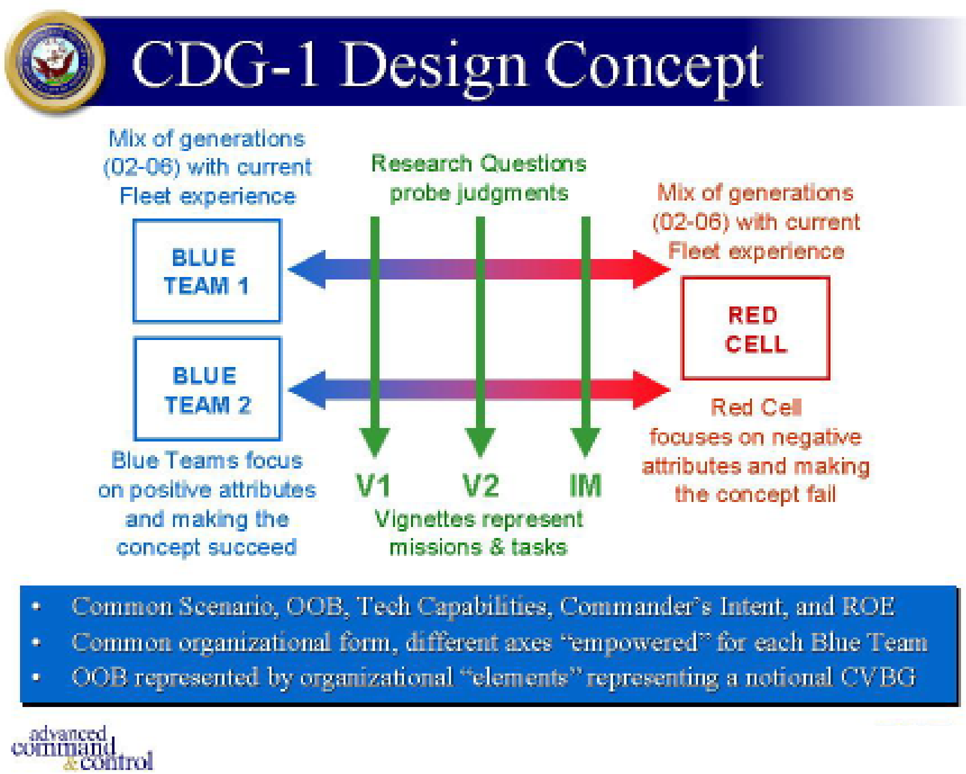


Figure 3. CDG-1 Design Concept.

Sensor Network Configuration in Electronic Attack

Investigating the concept of an optimum sensor network configuration for applications in electronic attack (EA) and suppression of enemy air defense (SEAD)(using the NRL Airborne Reactive Electronic Warfare Simulation (ARES)) is being pursued by Associate Professor Phil Pace, Department of

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Electrical and Computer Engineering. Pace and students are performing a sensitivity analysis of the solutions evolved by ARES in order to determine the robustness in the derived measures of effectiveness (e.g., sensitivity to system failures). They are also performing a sensitivity analysis to test the vulnerability of solutions to the environment (e.g., threat intensity, terrain, Integrated Air Defense System (IADS), etc.).

This work (in cooperation with the Applied Physics Lab and Naval Research Lab) continues the investigation of using ARES to determine an optimum sensor/jammer network configuration for the SEAD using the RT4, RT2 scenarios. This involves evaluating the sensitivity of the Measures of Effectiveness (MOEs) to small perturbations in the optimal solution (as derived by the genetic algorithm in ARES). For example, a trade space for

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EFFECTIVENESS OF THE HARM AS EMPLOYED BY THE F-16CJ AIRCRAFT AGAINST SERBIAN THREAT AND EARLY WARNING RADAR DURING OPERATION ALLIED FORCE

Ray Grant, Jr., DoD Civilian
Master of Science in Electrical Engineering-December 2000
Advisors: Phillip E. Pace, Department of Electrical and Computer Engineering and LtCol Mark A. Kanko, USAF, Air Force Information Warfare Center

The purpose of this thesis is to quantify the effectiveness of HARM Employment by F-16CJ aircraft against Serbian Threat and EW radars during OPERATION ALLIED FORCE (OAF) of March-June 99. The effectiveness was determined primarily through the use of "all-source" data to confirm the suppression/damage that target radars may have suffered and to assess general radar activity impacts as a whole during the conflict. The factors that enhance or degrade HARM effectiveness were also investigated as well as strike aircraft impacts where possible. Due to the impact that fog of war has on obtaining specific technical data, the emphasis of the report is on the apparent effect of the HARM on the enemy air defenses during the course of a mission (and campaign) and not the technical aspects of HARM performance during an engagement. However, modeling of several of the individual mission incidents was accomplished. In these cases, MESA 5.1.3 (Model for Electronic Support and Attack) was used to model the airborne receivers/ground emitters, calculate propagation losses, and verify scenario geometry to determine signal strength levels at the airborne receivers of interest.

EXPLORING TIME CRITICAL STRIKE IN FLEET BATTLE EXPERIMENTS

Research Associate Professor Shelley Gallup
Institute for Joint Warfare Analysis

One definition of "time-critical" refers to those targets that must be responded to within a target's "dwell time." This is the time during which the target is available to be engaged without moving from its present position, firing on friendly forces or making itself unavailable to attack by other means. Dwell time can refer to a matter of minutes or hours, but provides the time domain that time critical strike (TCS) processes must respond to.

Fleet Battle Experiments have explored the relationships between the time domain implied in TCS, command and control (C2) information technologies, organization, and processes. What has emerged is exceptionally complex.

Fleet Battle Experiment (FBE) Echo considered the TCS problem from the force protection perspective. This experiment was conducted in Oakland and San Francisco (with some play here in Monterey). Ships moored in the San Francisco harbor were to find and respond to potential TCS targets in an asymmetric environment. This meant that all of the naval forces in the vicinity of San Francisco had to somehow be included in a single information network which would provide the necessary information with regard to the local environment, and the means to respond. A centralized C2 organization was employed, and sensors (UAV sensor data, provided largely by the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) *Pelican*) provided imagery to all units within the network. A Full Dimension Protection cell on the *USS Coronado* made command decisions for weapons responses to TCS targets, which could include suspected SCUD-type of weapons, theater ballistic missile attack, and potential weapons of mass destruction. This experiment produced a set of technology requirements that must be met for a commander to make TCS decisions. For example, a technology that would produce an evaluation

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RT4, RT2 might involve four EA-6Bs, two Global Hawk UAVs, and six MALJs (miniature air-launched jammers). After the ARES genetic simulation, the optimum answer could be three EA-6Bs with Improved Capability (ICAP 3) receivers but with an increase in sensitivity (e.g., by 10 dB), two Global Hawks with receivers having -90 dBm sensitivity and an MALJ with a specific X-band jammer onboard. The derived measures of effectiveness (MOE) might be for example: total tracking time by EW (early warning) radars=20 s and total SAM (surface to air missile) engagements=20. A perturbation of the solution (e.g., no Global Hawk UAVs) is prepared and several vignettes are run for both RT2, RT4 to investigate the effect on the MOEs. This in turn will demonstrate the robustness of the MOEs to perturbations from the optimal solution.

Professsor Pace is also quantifying the effectiveness of the EA-6B stand-in, stand-off jamming capability to provide protection for strike aircraft using results from Operation Allied Force. Working with the Air Force Information Warfare Center, this thesis should be completed by March.

Spectral Imagery Assists in the Detection, Identification and Prioritization of Targets

A developmental technology that promises to assist in the detection, identification, and prioritization of targets is spectral imagery. Spectral imagery has been explored since the 1970s with multispectral sensors such as the suite of LANDSAT sensors. Multispectral sensors work in a manner similar to a color camera by taking

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OPTIMIZING TOMAHAWK STRIKES

Professor Gerald G. Brown, Department of Operations Research
Professor Richard E. Rosenthal, Department of Operations Research
Research Assistant Professor Alexandra M. Newman,
Department of Operations Research and Colorado School of Mines
Research Associate Anton A. Rowe, Department of Operations Research

When the U.S. National Command Authority authorizes a Tomahawk land attack missile (TLAM) strike, its aim points pass down through the chain of command via a regional Commander-in-Chief and thence to the Battle Group Tomahawk Strike Coordinator (TSC). The TSC predesignates these aim points to firing platforms. Predesignation considers geographic proximity of candidate platforms to aim points, the inventory and location of TLAMs aboard each platform, engineering limitations on the way in which and the rate at which a platform can prepare and fire particular missiles, flight route coordination among TLAMs, and other tactical concerns. The TSC must also take care to leave his combat units with maximal residual firepower after the strike, individually and as a battle group. Once a firing platform receives from the TSC its designated aim points and told what TLAMs to use, the actual selection of which particular TLAMs to fire may be adjusted by its Combat Information Center based on the last-minute status of the platform and its individual missiles.

Predesignation is a complicated decision problem, and an important one. TLAMs are expensive, about $600,000 each. They come equipped with several variations in guidance, propulsion, and payload, and we anticipate new variations with even more options. Surface combatants deploy with a variety of TLAMs preloaded in canisters. A missile salvo can be prepared and fired only if the designated TLAMs are located in canister cells that do not interfere with one another during preparation for launch.

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The Tomahawk land attack missile (TLAM) is the Navy's weapon of choice for striking shore targets from the sea. A TLAM launched from a surface combatant or a submarine is a reliable, unmanned, long-range, accurate weapon with sufficient payload to threaten almost any shore target. The Department of Operations Research at the Naval Postgraduate School has developed optimization-based decision support tools to optimize TLAM strikes from single firing units or entire battle groups. The idea is to execute each strike efficiently while retaining residual firepower, and while considering a number of other essential details. By applying mathematical modeling, the result is the ability to plan fleet and theater-wide strikes in seconds.

FEATURED PROJECT

T.V.E. DISPLAY: A PROPOSED SHIPBOARD NAVIGATION DISPLAY TO ENHANCE CONNING OFFICERS' SITUATIONAL AWARENESS

Assistant Professor William K. Krebs, Department of Operations Research
LCDR Thomas V. Evanoff, USN
Thomas McCord, Department of Mechanical Engineering
Dr. A. J. Ahumada, NASA Ames Research Center

Surface Warfare Officers (SWOs) report that maintaining station 3000 yards astern of an aircraft carrier during low visibility is one of the more difficult tasks for the crew. For centuries, sailors used navigation aids, such as flags, smoke and lights, to signal and maneuver around ships and other obstacles. Although these visual aids along with modern radar and voice communications improve conning officers' situational awareness, these aids are not 100% reliable to detect an approaching hazard. On October 14, 1996, the aircraft carrier *USS Theodore Roosevelt* and guided-missile cruiser *USS Leyte Gulf* collided while conducting pre-deployment exercises in the Atlantic Ocean. The accident occurred on a moonless night at approximately 0300 in two-foot seas. The cruiser was on station approximately 4,000 yards astern of the carrier. The carrier was conducting three significant events: testing a communications system; maneuvering in a zigzag pattern; and conducting propulsion plant drills that included maneuvering in reverse. The radio communications between the two ships ceased and the crews had to use flashlights to transfer information. This outdated mode of communication was slow, in fact it took 25 minutes for one message to be received by the bridge. At the same time, the cruiser's commanding officer was in the Combat Information Center assisting in the recovery of a helicopter. Due to communication problems between the two vessels, the cruiser was not aware of the carrier drills. A short time later, the aircraft carrier ceased zigzag maneuvers, and without warning the aircraft carrier went to emergency back full. The two ships collided with a closing speed of 20 knots. The mishap investigation board stated that the collision was caused by a number of human-factor failures between both bridge teams, with the primary causal factor being failure to communicate intentions.

Fortunately, the *Theodore Roosevelt* and *Leyte Gulf* mishap is rare; however SWOs often maneuver in close formation with an aircraft carrier which may increase the likelihood of a collision. During a plane guard task, the aircraft carrier is launching and recovering aircraft while the surface combatant is positioned a few thousand yards astern of the carrier. The conning officer's attention is divided between gauging the location of the aircraft carrier, monitoring aircraft traffic,

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About the INVESTIGATORS

William "Kip" Krebs is an Assistant Professor in the Department of Operations Research (OR). He earned his M.A. and Ph.D. in Experimental Psychology from the University of Louisville. Prior to joining the OR faculty, Dr. Krebs was an Aerospace Experimental Psychologist in the United States Navy for five years. Dr. Krebs is principal investigator on several research projects including multi-sensor displays, low-level visual perception, and developing computational models for human vision. Currently, he is a Scientific and Technical Advisor for Human Factors at the Federal Aviation Administration, Washington, D.C.

William "Kip" Krebs

LCDR Thomas V. Evanoff received a M.S. in Operations Research from the Naval Postgraduate School in December 1999 and his B.S. in Mechanical and Aerospace Engineering from Illinois Institute of Technology in1987. He was awarded the Military Operations Research Society (MORS) Award for best thesis entitled "Design and Analysis of a Shipboard Visual Navigation Aid for Vessels in a Formation: Tactical Vectoring Equipment." He is currently assigned as the Executive Officer of *USS Mobile Bay* (CG 53).

Thomas McCord received a B.S. degree in General Engineering from the U.S. Military Academy in June 1969 and a

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PROPOSED SHIPBOARD NAVIGATION DISPLAY, *continued from page 6*

searching the water for other vessels, and avoiding foreign obstacles. To accomplish these tasks, the combatant's conning officer must estimate the aircraft carrier's distance and bearing by visual, auditory, and radar information; however, in certain situations these cues may be ambiguous which may lead to a loss of situational awareness by the conning officer. To reduce the loss of situational awareness, we propose that a Tactical Vectoring Equipment (TVE) display be mounted on the stern of the aircraft carrier to assist shipboard conning officers when maneuvering in a battle group formation (Evanoff, 1999). The TVE display consists of six red and white lights spaced approximately nine feet apart mounted on the stern of the aircraft carrier (Figure 1). The TVE's position on the carrier's stern will be clearly visible to the escort ship conning officer, but will be invisible to the carrier pilots during flight operations.

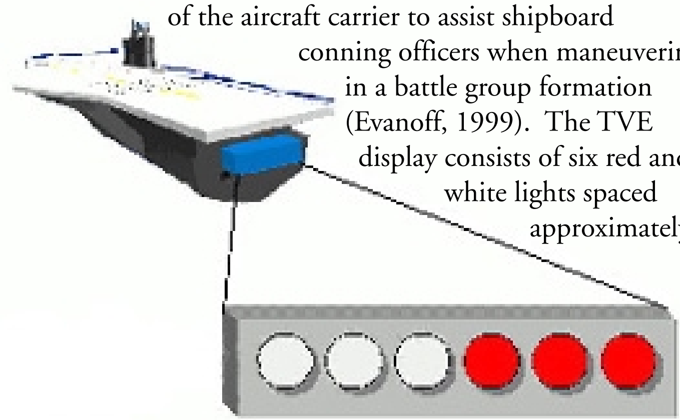

Figure 1. The TVE Shipboard Navigation Display. The TVE display consists of a horizontal line of six bicolor (red and white) lights spaced approximately six feet apart on the stern of the carrier.

To test the effectiveness of the TVE display, Krebs, Evanoff, and Sinai (2000) modeled the aircraft carrier and plane guard vessel in a virtual environment. The TVE navigation display is similar to the aviation runway displays that assist pilots during low illumination or poor weather conditions. These landing displays may use Fresnel lenses or lasers (Martenak, 1999) to display multi-colored lights to the pilot to indicate the plane's vertical position in relation to the runway. For example, if the pilot's glide path angle were too low then the runway display would appear red indicating to the pilot to increase power. The TVE display uses similar principles, except the shipboard display is positioned horizontally on the stern of the carrier. The position of the carrier relative to the combatant, the TVE will illuminate different combinations of red and white lights to indicate the escort ship's relative position to the stern of the carrier. The TVE will provide the conning officer instantaneous, continuous, and positive visual feedback of the carrier's position relative to the cruiser. For example, if the cruiser was 200° left of the stern of the carrier,

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About the INVESTIGATORS, *continued from page 6*

Thomas McCord

M.S. degree in Engineering Management from the University of Tulsa in May 1982. He served as an Army helicopter pilot in Vietnam and is a Registered Professional Mechanical Engineer in the state of California. He is currently employed as the Laboratory Manager in the Department of Mechanical Engineering at the Naval Postgraduate School.

Albert J. Ahumada, Jr. is a research psychologist developing computational models for human vision at the NASA Ames Research Center. Academia, government, and industry recognize him as one of the top researchers in vision with a special interest in human factors. He received his B.A. in Mathematics from Stanford University in 1961 and his Ph.D. in Psychology from the University of California, Los Angeles in 1967. He was an Assistant Professor of Psychology at the University of California, Irvine from 1967 to 1975 and a Senior Research Associate at Stanford University from 1975 to 1980. He has been a Research Psychologist at NASA Ames Research Center since 1980. He has published articles in the areas of neurophysiology, statistical methods, audition and visual perception. He is a visiting professor in the Department of Operations Research.

FEATURED PROJECT

TOWARD UNDERSTANDING NAVY KNOWLEDGE FLOW

Assistant Professor Mark E. Nissen
Department of Systems Management

Knowledge is power. This saying has long been ascribed to successful individuals in the organization, but today it is recognized and pursued at the enterprise level through a practice known as knowledge management. Although knowledge management has been investigated in the context of decision support systems and expert systems for over a decade, interest in and attention to this topic have exploded recently. For example, many prominent technology firms now depend upon knowledge-work processes to compete through innovation more than production and service, and Peter Drucker writes, "knowledge has become the key economic resource and the dominant—and perhaps even the only—source of comparative advantage." This follows his assertion that increasing knowledge-work productivity represents the great management task of this century, on par with the innovation and productivity improvements made through industrialization of manual-work processes. Brown and Duguid add, "organizational knowledge provides synergistic advantage not replicable in the marketplace." Indeed, some forecasts suggest knowledge work will account for nearly 25% of the workforce in the early 21st century. And partly in anticipation, fully 40% of Fortune-1000 companies have established the role of Chief Knowledge Officer (CKO) in their companies.

The U.S. Navy has also appointed a CKO, and the leadership is working to revise its strategy and tactics around knowledge through a new emphasis on knowledge-centric warfare. With this new thinking, the *knowledge warrior* concept is now being developed along with the *knowledge-centric organization*, albeit with minimal science or theoretical foundation involved or available for guidance. An extension

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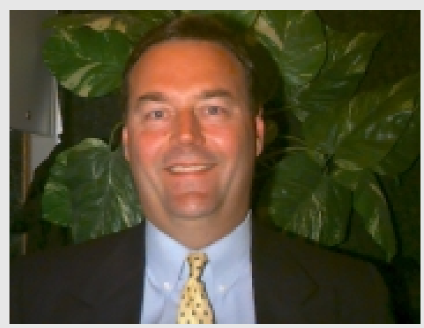
About the INVESTIGATOR

Mark E. Nissen is an Assistant Professor of Acquisition Management and Information Systems in the Department of Systems Management. He received his Ph.D. in Information Systems from the University of Southern California (USC) after completing a M.S. in Systems Management from USC and a B.S. in Business Administration at the University of California-Berkeley. Dr. Nissen had considerable management experience in high technology industries before joining the faculty of NPS.

His research focuses on the investigation of knowledge systems for enabling and managing change in areas such as process innovation, electronic business and knowledge flow. Recently he has been investigating knowledge systems to innovate processes in the acquisition domain, and he is currently involved with intelligent supply chain agents, as well as techniques and technologies for the capture and distribution of knowledge in very-large enterprises. Nissen's publications span both the information systems and acquisition fields, and he has recently published his first book, entitled *Contracting Process Innovation*. He also serves as Program Manager for the External Acquisition Research Program, which is sponsored by the Defense Acquisition University.

Dr. Nissen is the most recent recipient of the Carl E. and Jessie W. Menneken Faculty Award for Excellence in Scientific Research. The purpose of the award is to recognize highly meritorious research by a junior NPS faculty member, which has identifiable impact on Navy or other Department of Defense technology.



Mark E. Nissen

Since his arrival at NPS, Dr. Nissen has made numerous outstanding contributions to the research field of knowledge systems. Drawing from theory and application in artificial intelligence, and using computer systems, he has successfully focused his technical research on high-level cognitive processes involved in military decisionmaking. As a result his research is of particular value to DoD and DoN programs on the Revolution in Military Affairs. Dr. Nissen has advised over two dozen master's thesis students and several doctoral students in his four years at NPS, and he has successfully integrated his research into the classroom. His publication record, which includes nineteen refereed journal articles, reflects his outstanding productivity as a researcher.

FEATURED PROJECT

TOWARD UNDERSTANDING NAVY KNOWLEDGE FLOW, *continued from page 8*

of network-centric warfare, which itself represents relatively-new military thinking, there is a realization in the Navy that simply connecting sensors, weapons, databases and people through a network is not enough. Rather, knowledge possessed by warfighters provides the basis for sustainable competitive advantage, and such knowledge requires effective organization and rapid, dispersed distribution.

With this, it is apparent that *knowledge flow* is critical to current and future naval warfare. But without research to develop basic knowledge and understanding of knowledge flow in the very-large enterprise, current and future attempts to design and build effective systems and processes for automation and support of knowledge work will remain relegated to the kind of unguided, trial-and-error practice observed at present. This current situation is far from the desired state of *engineering* such knowledge systems and processes.

The featured project outlined in this article seeks to develop such basic knowledge and understanding in terms of Navy knowledge flow. Although research toward this end is in a very-early stage, it has been attracting attention in Academe, the Pentagon and the Fleet alike. This short, high-level article outlines some of the key elements, and selected references to journal papers and student theses are included at the end for the interested reader. The balance of this article follows with a brief summary of key background concepts and an overview of current work. The article concludes with an agenda for continued research along these lines.

Background Concepts

Three background concepts from knowledge management research are summarized here. First, it is important to understand the knowledge hierarchy. In the Navy and industry alike, most information technology employed to enable and support knowledge work targets data and information, as opposed to knowledge itself. Knowledge, almost by definition, lies at the center of knowledge work, yet it is noted as being quite distinct from data and information. Indeed, many scholars conceptualize a hierarchy of data, information and knowledge. As illustrated in Figure 1, each level of the hierarchy builds on the one below. For instance, data are required to produce information, but information involves more than just data (e.g., need to have the data in context). Similarly, information is required to produce knowledge, but knowledge involves more than just information (e.g., it enables action). We have notionally operationalized this hierarchy using two dimensions—abundance and actionability—to further differentiate between the three constructs.

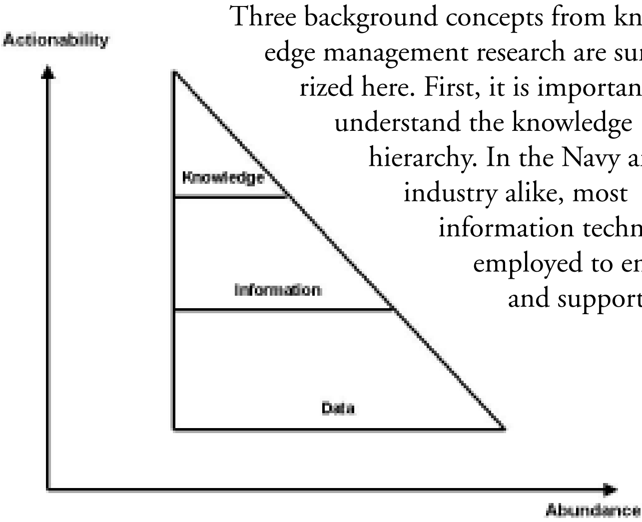


Figure 1. Knowledge Hierarchy.

Briefly, data lie at the bottom level, with information in the middle and knowledge at the top. The broad base of the triangle reflects the abundance of data in most organizations, with exponentially less information available than data and even fewer chunks of knowledge in any particular domain. Thus, the width of the triangle at each level reflects decreasing abundance as one progresses from data to knowledge. The height of the triangle at each level reflects actionability (i.e., one's ability to take appropriate action). Converse to their abundance, data are not particularly powerful for supporting action, and information is more powerful than data. But knowledge supports action directly, hence its position at the top of the triangle.

Second, one can observe a sense of process flow or a life cycle associated with knowledge as it is created and distributed through an enterprise. For instance, a popular view of this life cycle outlines six phases: knowledge 1) creation, 2) organization, 3) formalization, 4) distribution, 5) application and 6) evolution. Although the knowledge management life cycle is generally described as a sequence of activities, however, in practice the performance is quite iterative, as each activity is often revisited multiple times.

The cyclical nature is more readily discernable when the life cycle is presented as a circle, as opposed to a linear sequence of activities, as depicted in Figure 2. Notice the three knowledge-sharing activities—knowledge organization, formalization and distribution—that are adjacent on the right-hand side of the cycle. These activities correspond with relatively-good support from extant information technologies and management practices, so they are grouped under the "Class I" heading in the figure. Such technologies and practices are

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THE NAVAL POSTGRADUATE SCHOOL'S SOFTWARE ENGINEERING PROGRAM

The Role of Software Engineering

Today's fast-moving technology demands quicker and more reliable methods to develop software systems that meet user needs. Software has become the "magic glue" that holds the components of every complex system together, the "magic putty" that fills the cracks between these components, and the "magic mold" that gives the system an outward "look" matching the users needs. However, as pointed out in the *Scientific American*, "…despite 50 years of progress, the software industry remains years - perhaps decades - short of a mature engineering discipline needed to meet the demands of an information-age society."[2]

"An effective innovation process requires continuous learning – a means of interaction and exchange that evaluates goals, operational lessons, exercises, experiments, and simulations – and that must include feedback mechanisms. The Services and Combatant commands must allow our highly trained and skilled professionals the opportunity to create new concepts and ideas that may lead to future breakthroughs. We must foster the innovations necessary to create the joint force of the future."[1]

Software engineering is an emerging discipline aimed at addressing the problems that arise in the building of large software systems. The major challenge in building these systems is that no one fully understands what the systems are supposed to do. Software engineering differs from other engineering disciplines in that almost all other engineering disciplines deal with tangible goods that are made of atoms, while software engineering deals with an intangible product that is made of "bits." Atoms abide by physical laws - bits do not. Instead, we must first develop a set of man-made laws and formalisms to govern the creation of software. These laws and formalisms require experimental validation to ensure that they correspond to reality. Fundamental research is vital to the discovery of new techniques necessary for defining, abstracting, and modeling real world problems. Research leads to the ability to automate the process of building practical and economical solutions.

Establishment of the NPS Software Engineering Program

It is the continuing goal of the Naval Postgraduate School's software engineering faculty to maintain one of the nation's preeminent software engineering programs. Three key capabilities serve as enablers of this goal: cutting-edge research, definitive education, and leadership in technology transfer and insertion. The NPS program is built upon 15 years of software engineering research aimed at the discovery of the models, theories, methods, and tools for building large systems. Research efforts in rapid prototyping, design methodologies, specification techniques, design languages, modeling and scheduling of real-time systems, requirements validation, software reuse, software architecture, software evolution, software change management, and software reliability models and metrics have resulted in many pioneering contributions in these areas. These contributions have resulted in a new software engineering paradigm that allows large software systems to be engineered on a logic-based foundation, so that software systems can be defined using formal models to enable computer aided analysis and automatic software generation. These research efforts helped establish NPS as the highest-ranking software engineering program in 1994 among all academic institutions across the nation[3]. The work on Computer Aided Prototyping earned Professor Luqi, Director of the Software Engineering Automation Center, the IEEE Technology Achievement Award in 1997.

The software engineering faculty play an important leadership role in the software engineering community at large. They serve as editors and board members of the major software engineering journals, program chairs and committee members of the major international conferences, and reviewers for proposals of major DoD and federal research programs. Their contributions to the community are evidenced by the award of IEEE Fellow status to three faculty members, Professor Jon Butler, Department of Electrical and Computer Engineering, Professor Luqi, and Professor Norm Schneidewind, Information Systems Academic Group, and the recognition of two other faculty members, Professor Valdis Berzins, Department of Computer Science, and Visiting Professor Du Zhang, as IEEE Senior Members.

In 1995, the Assistant Secretary of the Navy for Research and Development requested that the NPS software engineering faculty address the need for software engineering education tailored to Naval officers and the Navy's civilian workforce. NPS rose to the challenge and established DoD's first master's level program that same year. This program

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SOFTWARE ENGINEERING PROGRAM, *continued from page 10*

provides a means for students to earn a Master of Science degree in Software Engineering (MSSE). The program was made available both on-campus and by distance learning in order to mitigate the impact on the sponsoring agency's manpower. Within the MSSE program a student can specialize in either combat systems or computer science. In addition, the program offers specialized course work in the software systems safety aspects of weapon system software development. Courses may be taken as a full-time student or via distance learning. These programs fill a wide range of needs among DoD personnel involved with software engineering and enable these individuals to become experts in software engineering, greatly enhancing their contributions and value to their sponsoring agency.

As a direct consequence of striving to maintain its position as a national leader in Software Engineering, NPS is now positioned to be the leading knowledge provider for the Navy and DoD software practitioners. No core competency of the Joint Vision 2020 can be attained or maintained without dependable and predictable software systems. Indeed, information dominance, a critical enabler of full spectrum dominance, is unattainable without well-engineered software. The mission capability of twenty-first century warfighters depends upon the proper definition and construction of software systems. For this reason it is urgent for the Navy to train and educate a premiere software engineering workforce.

The Software Engineering Program at the Naval Postgraduate School provides military and government graduate students with an opportunity to learn all aspects of software development along with the skills needed to efficiently and reliably plan and manage large-scale software systems using the best available tools. These skills are essential for officers and civilians responsible for acquisition, development, and/or maintenance of military software.

The Combat Systems Subspecialty Option is a systems engineering program modified to emphasize DoD computer-based systems and applications. This program is designed to meet Navy needs beyond software by treating whole systems issues. The Computer Science option is a curriculum designed to provide the officer with the technical knowledge and skills necessary to specify, evaluate, and manage computer system design; to provide technical guidance in applications ranging from data processing to tactical embedded systems; to educate the officer in the analysis and design methodologies appropriate for hardware, software, and firmware; and to provide the officer with practical experience in applying modern computer equipment and research techniques to solve military problems.

More than 40 master's students have graduated from the Software Engineering curriculum and 70 more are progressing toward graduation. Building upon the success of the masters program and focusing on the vital need for Ph.D. caliber leaders to direct the progress being made in DoD research laboratories, NPS established one of the leading software engineering doctorate programs in the nation. The Ph.D. program in Software Engineering is specifically designed for DoD software practitioners who want to acquire the skills and knowledge to perform state-of-the-art research on issues related to the development and evolution of large, complex software systems; to intelligently manage the research of other software practitioners; and to assist in the assessment and planning of systems development to meet future DoD needs. It offers software professionals a unique program of study and advances software engineering principles and technology vital to DoD researchers and program managers. As with the M.S. program, delivery is by distance learning as well as on campus. The vitality of the program can be clearly measured by the granting of the program's first doctorate degree within the first three years of its existence. Over fifty candidates are now enrolled in the program. It can reasonably be expected that these candidates will make a significant contribution to their sponsoring agency's mission performance upon the completion of their program. Furthermore, the process of accreditation of the program by the Accreditation Board for Engineering and Technology (ABET) has been initiated. (More information on the various Software Engineering Programs may be found at the Software Engineering website, http://cs.nps.navy.mil/~se.)

The Impact of Research on Software Engineering Education

Research, in addition to being valuable to the development and fielding of advanced weapons and command systems, also has a significant role in the establishment and growth of an effective curriculum at NPS. Its impact is especially evident within the NPS software engineering research program. Truly energetic research spawns dynamic education and classroom interaction. Software engineering is a fast moving discipline. Graduate education quickly derives the benefits of research results from diverse subjects including real-time software, computer-aided rapid prototyping, software evolution, and software reuse. Utilizing state-of-the-art research results to

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SOFTWARE ENGINEERING PROGRAM, *continued from page 11*

supplement graduate course material is an important way to expand classical classroom knowledge, ensuring the continuing quality of the courses. The NPS software engineering faculty developed a set of advanced courses based upon their research results. These courses teach students the advanced technologies, theoretical issues, and new research findings in computer-aided software development, re-engineering, and evolution. The underpinning of these courses is the use of logic and formal notations in the modeling and design of software. Our research in requirements engineering and software design show that while propositional logic lacks the expressive power to specify the dynamic behavior of software, a minor extension to the first order logic is sufficient in specifying software behavior. Our courses have been evaluated by the Software Engineering Institute (SEI) in 1989. They concluded that our logic-based approach was right on target and well ahead of the state of practice.

Student skills are honed by their participation in many state-of-the-art research projects being carried out by NPS software engineering researchers. These projects provide students an opportunity to be at the forefront of knowledge generation in this area, while training them in advanced technological research techniques. These projects also allow students to contribute their specialized knowledge of DoD activities and needs to the software engineering academic projects while they gain first hand experience on emerging new technologies relevant to DoD problems. By participating in DoD sponsored research projects, the software engineering faculty bring innovative approaches to DoD problems. This focus also results in highly relevant thesis efforts while developing critical thinking skills in tomorrow's military leaders. Some recent theses have used software engineering principles to enhance the software infrastructure of C4I applications, to prototype an emergency response system, an autopilot system, and an aircraft automatic landing system, and to develop a real-time network system for synchronization of time-ordered encrypted data systems. These systems all required very high reliability in their software and it is in these types of systems where software engineering research, education, and training can save countless dollars and lives. Research, coupled with education, results in innovation. The program has also reaped the benefits of many post-doctoral National Research Council researchers. These individuals have brought many new ideas to the school and supported the software engineering faculty by advising the Ph.D. students.

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SOFTWARE ENGINEERING RESEARCH CENTER (SEAC)

Software is now an essential component of every facet of the military mission. Not only is it included in our own warfighting systems, but also it has become the focus of warfighting efforts by our potential adversaries as well as our allies. Software drives our airplanes, ships, and missiles. Software brings us much of our capability. Software is used in the planning process. Software ensures the reliability of our logistics. The information derived from software systems enables our most critical decisionmaking. It is probably not an exaggeration to state that the next war may be won by whomever has the best software systems. The Naval Postgraduate School is in a unique position to improve all aspects of the software engineering process and to transfer improvements via its comprehensive education programs.

The Software Engineering Automation Center (SEAC) brings together leaders in academia, industry, and government to collaborate on the development and application of core disciplines and computer aided support that may be applied to the software production process. It brings to bear the innovations, lessons learned, and techniques developed over more than a decade of research into the problems associated with generating "correct" software. It is the "reasoning together" of professionals from many disciplines that is resulting in a set of principles, methods, tools, and standards to improve the efficiency and predictability of software-intensive systems development.

The overarching objective of the Center is the development of more effective methods for the performance of software engineering tasks. This includes the development of models and tools to automate selected subtasks and automated decision support for software analysis and synthesis. The Center provides a forum for the discussion and investigation of emerging software development tools that demonstrate the utility of applying engineering discipline to the

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SOFTWARE ENGINEERING PROGRAM,

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The Computer-Aided Prototyping Technology

Many of the research projects have involved the application of the Computer-Aided Prototyping System (CAPS) to solve DoD problems. CAPS is a rapid prototyping environment for evaluating complex software systems before they are implemented in the field. As in other engineering disciplines, software engineering requires the building of models and prototypes to assess new systems before deployment. Especially in DoD applications, failure of software after deployment is costly, both monetarily and in the risk of human lives. It has been estimated that prototyping alone results in a 40% cost savings within the life cycle of the system[4]. The iterative prototyping process employed by CAPS is shown in Figure 1.

First the requirements of the software system being constructed are specified. Using these requirements, other software already developed and stored in a software repository, and automated engineering tools embedded in the CAPS system, an executable prototype is generated in a target programming language such as Ada, C++ or Java. Based upon evaluation of the prototype results, the requirements may be found to be incomplete or incorrect and require modification. The prototyping cycle is then repeated until the prototype

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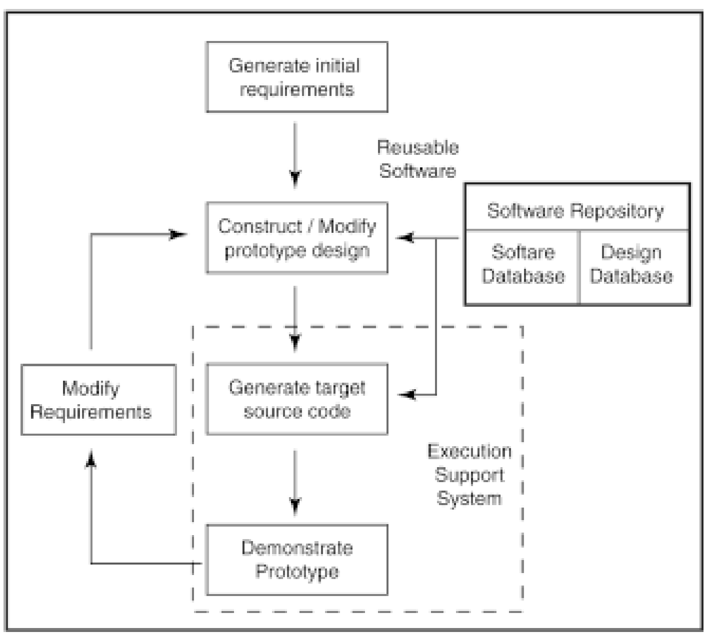

Figure 1. Iterative protoyping process in CAPS.

SOFTWARE ENGINEERING RESEARCH CENTER,

continued from page 12

creation and maintenance of mission-critical software. The Center orchestrates the research of NPS faculty relevant to the advancement of engineering discipline as applied to computer-based systems. It supports class projects and student theses activities in software engineering, facilitating the direct application of emerging software engineering technologies and research techniques acquired by Ph.D. and Masters of Science students to current Navy and DoD problems. These projects and activities provide opportunities for NPS students to obtain in-depth software engineering education focused on issues of direct concern to the Navy, the DoD, and their professional career.

The SEAC conducts research on software automation, focusing on such issues of vital concern to the DoD as improving software interoperability, flexibility and reliability while reducing costs and project risks. Software automation strives to apply computer-aided requirements definition and specification, problem modeling, rapid-prototyping, and test, verification, and validation methods to software development and maintenance. Each of these activities focuses on the desire to produce efficient and cost effective systems which satisfy the needs of the customer. The accurate translation of customer needs into system requirements is a fundamental task of software engineering. Automation of aspects of that process offer opportunities to reduce system costs by increasing the likelihood that the system solves the customer's real problem.

The conduct of research on software automation, with specific application to DoD needs, ensures the Center remains a force in the furtherance of software engineering practices within the academic community. The specific purposes of its research are the development of effective methods, models, and tools to automate software production and maintenance. SEAC research addresses the following skills, knowledge, and abilities:

- Formal models for specifications and requirements analysis
- Prototyping and CASE technology
- System integration and interoperability
- Software architecture

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SPACECRAFT RESEARCH AND DESIGN CENTER

Background

The Spacecraft Research and Design Center consists of four state-of-the art laboratories: Spacecraft Attitude Dynamics and Control Laboratory, Smart Structures Laboratory, FLTSATCOM Satellite Laboratory, and the Spacecraft Design Laboratory. Professor Brij N. Agrawal, Director of the Center, began the development of these laboratories in 1989. He came to NPS after working for twenty years in the research and development of communications satellites at Communications Satellite Corporation (COMSAT) and International Telecommunications Satellite Organizations (INTELSAT). In 1999 a water main break caused extensive water damage to equipment, experiment set-ups, and the room structure. With the help of the Navy, these laboratories went through a second major refurbishment phase in 1999 through 2000 and are now fully operational.

The laboratories are used primarily by Space Systems students and faculty for instruction and research. The labs have several unique capabilities for an academic institution and students from other departments at the Naval Postgraduate School, such as Mechanical and Electrical and Computer Engineering, and other universities, such as Columbia University and Milan Polytechnic, have used the laboratories for their research work. The emphasis has been on providing students with hands-on experience in the design, analysis, and testing of space systems and sub-systems and to provide students with the facilities to do experimental research. During the last ten years, four Ph.D.s, seven Engineers, and thirty-four Master's of Science (M.S.) theses have been affiliated with the labs. In addition to the student research, five National Research Council Postdoctoral Research Fellows have conducted their research, and over 50 technical papers have been published in refereed journals and conference proceedings. Currently, two Ph.D. students and five M.S. students are doing research work for their theses.

The labs' unique facilities, experimental equipment and capabilities are discussed in the following paragraphs.

Spacecraft Attitude Dynamics and Control Laboratory

The Spacecraft Attitude Dynamics and Control Laboratory is used to perform research on developing improved control techniques for attitude control of flexible spacecraft and flexible robotic manipulators. Since the lab's inception in 1989, the emphasis on research has been to develop improved control laws for fast slew maneuver of flexible spacecraft and minimize vibration and settling time at the end of slew maneuver. The impetus for this research has been the requirement for reconnaissance spacecraft with fine pointing and fast slew maneuver for retargeting. For several future reconnaissance spacecraft, this problem is becoming critical as the slew maneuvers are faster, the spacecraft are becoming more flexible, and pointing requirements are getting tighter. The laboratory has three simulators to validate the improved control techniques experimentally: Flexible Spacecraft Simulator, Three-Axis-Attitude Simulator, and Space Robot Simulator.

- Flexible Spacecraft Simulator (FSS): The FSS (Figure 1) simulates attitude motion in pitch axis of a flexible spacecraft. It consists of a central rigid body representing the spacecraft central body and a flexible appendage representing a reflector with a flexible support structure. This system is floated on air pads over a granite table to simulate a micro-gravity environment. The actuators are thrusters with air supply from a compressed air bottle and a reaction wheel. The sensors are rotary variable differential transformers (RVDTs), a rate gyro and an overhead camera as a position sensor. A dSpace system is used for the real time controller. This simulator has been used extensively for developing control laws for single axis slew maneuvers of flexible spacecraft.

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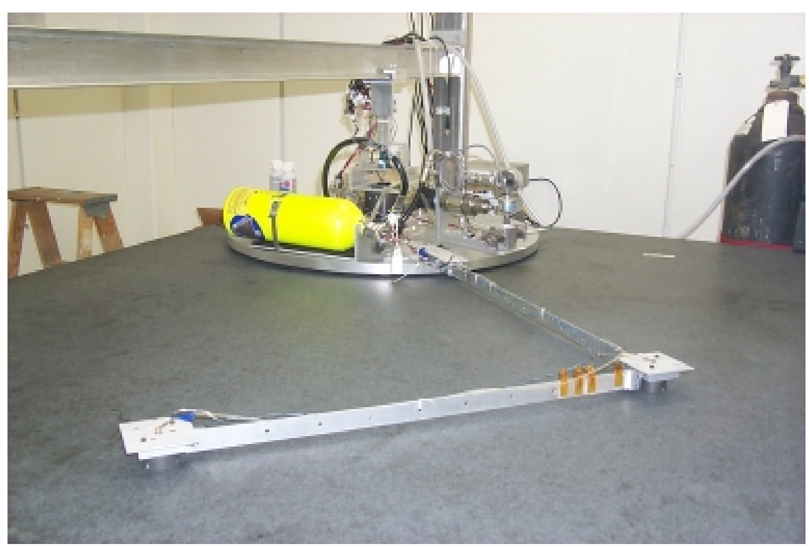

Figure 1. Flexible Spacecraft Simulator.

SPACECRAFT RESEARCH AND DESIGN CENTER, *continued from page 14*

- Three-Axis-Attitude Control Simulator (TACS): The TACS (Figure 2) simulates a free-floating spacecraft with a platform that incorporates air thrusters, rate gyros, sun sensors, magnetometers, three reaction wheels and a laptop computer. The platform floats on a spherical air-bearing stand thus giving the simulator three degrees of freedom for attitude control. Matlab/Simulink with a Real Time Controller is used for real time control of the system. The simulator became operational in December 2000 and will be used for developing control laws for three-axis slew maneuvers.
- Space Robot Simulator (SRS): The SRS (Figure 3) consists of a two-link manipulator with rigid and flexible links. The SRS is mounted on a granite table by four air pads. A PC Pentium III/500 MHz, hosting a DS-1103 PPC controller board, is used for the real time control. The control algorithm, developed in Matlab-Simulink, is compiled and downloaded to the PPC board using dSpace System version 2.1. Research has been done on evaluating Bang-Bang; input shaped, and smoothed Bang-Bang torque profiles for slew maneuver to reduce settling time.

Figure 2. Three-Axis-Attitude Control Simulator.

This laboratory has been used extensively by students for their thesis work (two Ph.D., four Engineers, and seven M.S. theses) and by Postdoctoral Fellows. Research conducted in the lab has resulted in the publication of twenty-six technical papers in refereed journals and conference proceedings.

Several novel control techniques have been developed. Professor Agrawal, Robert McClelland (DoD civilian, Mechanical Engineer, March 1994), and Research Assistant Professor Gangbing Song developed the Pulse Width Pulse Frequency Modulated Thruster Control System for slew maneuvers of flexible spacecraft to minimize settling time. Professor Agrawal and Research Assistant Professor Hyochoong Bang developed a robust closed-loop control design for spacecraft slew maneuver using thrusters. Visiting Researcher Tong Huang and Professor Agrawal developed a neural network control algorithm for attitude control of a flexible spacecraft. Capt Gary E. Yale, USAF (Ph.D. Aeronautical and Astronautical Engineering, September 1993) and Agrawal developed a Lyapunov controller for control of cooperative space manipulators. LT

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Figure 3. Space Robot Simulator.

SPACECRAFT RESEARCH AND DESIGN CENTER, *continued from page 15*

George Janiver, IV, USN (M.S. Electrical Engineering and M.S. Aeronautical Engineering, December 1993) and Agrawal developed an adaptive control system for a space robotic manipulator. Using the SRS, Agrawal with Visiting Professor Bernelli-Zazzera from the Milan Polytechnic Institute evaluated experimentally the Bang-Bang, input shaped, and smoothed Bang-Bang torque profiles for slew maneuver to reduce settling time.

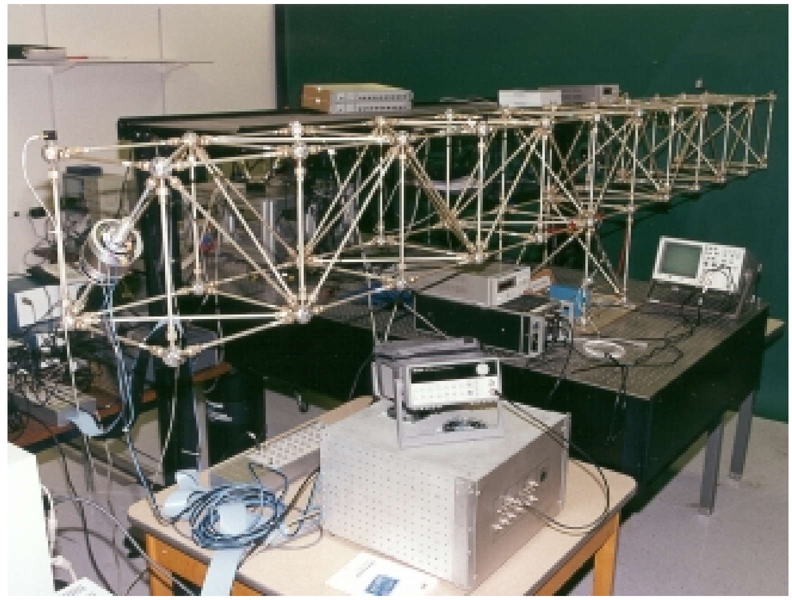

Figure 4. NPS Space Truss.

Smart Structures Laboratory

This laboratory is used to perform research on active vibration control, vibration isolation, and fine pointing by using smart sensors and actuators. This is an area of great interest for future reconnaissance imaging spacecraft. The pointing performance requirements of the optical payloads are increasing and the vibration sources on the spacecraft are also increasing due to large flexible structures, devices such as cryo-coolers, reaction wheels, solar array drives, fluid pumps, and other mechanical devices. Shape control of inflatable structures is also an area of great interest to DoD. The smart sensors and actuators used are piezoelectric, shape memory alloys, voice coils, and fiber optic systems. This laboratory also supports courses in structures and dynamics and smart structures. The development of this laboratory was initiated in 1995 and the following experiments are currently ongoing.

- NPS Space Truss: The NPS Space Truss (Figure 4) is used for testing control algorithms for active structural vibration control and vibration isolation. The overall dimension of the truss is 3.76 m long, 0.35m wide, and 0.7 m tall. The fundamental frequency of the truss is 15 HZ. Two piezoceramic struts are installed as actuators near the base of the truss. The output force for the actuator is 0-2100 N and the displacement range is 0-90µ. A linear Proof Mass Actuator, located at the left end of the truss, generates the disturbance. The output force is 0-3 lbs in a frequency range of 10-1000Hz. The research in this area is done in cooperation with Professor Young Shin, Department of Mechanical Engineering.
- Ultra Quiet Platform (UQP): The UQP (Figure 5) is used for testing control algorithms for vibration isolation of an imaging payload. It is configured similar to a six degree of freedom "cubic" Stewart Platform. Each strut consists of a piezoceramic stack actuator (PZT) and a geophone sensor. The PZT converts control signal voltages to a physical movement of the active strut. The maximum displacement of the actuator is 50µ, which is sufficient for vibration isolation application, but not for platform pointing and steering. The source of the disturbance is an Aura Bass shaker. The control function is performed by a dSpace DSP (digital signal processing) system. Research in this area is done in cooperation with Professor R. Longman from Columbia University and Associate Professor Roberto Cristi, Department of Electrical and Computer Engineering at NPS.

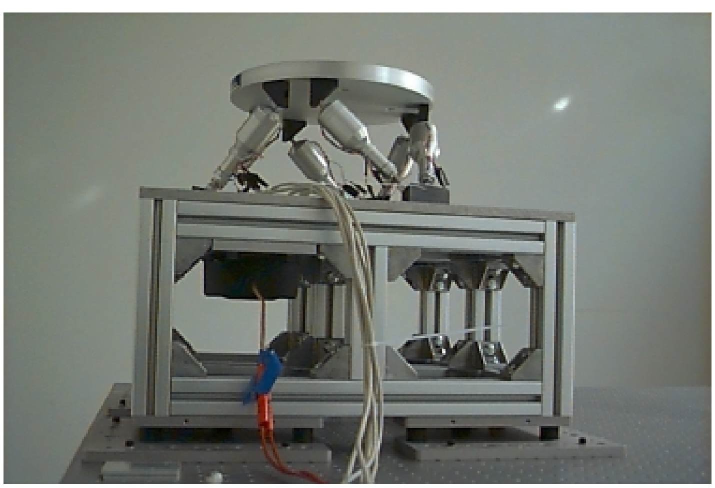

Figure 5. Ultra Quiet Platform (UQP).

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SPACECRAFT RESEARCH AND DESIGN CENTER, *continued from page 16*

- Positioning Hexapod: The Positioning Hexapod (Figure 6) is also used for testing control algorithms for both vibration isolation of an imaging payload and fine steering. It is based on the arrangement of six self-supporting electromagnetic voice coil actuators with in-line accelerometers that enable the control of high frequency vibration. Lower frequency steering and vibration isolation is provided by the use of a laser-photo-diode based 2-axis position detecting system and eddy current position sensors. The system can deliver over 5.7 mm of axial/position travel, 20 mm of lateral motion, 2.5 degree of-tilt motion and 10 degree of twist. Research in this area is also done in cooperation with Professor Cristi.
- Shape Control of a Honeycomb Beam Using Shape Memory Alloy Wire: This experiment is used to study the shape control of honeycomb structures using shape memory alloy (SMA) wires (Figure 7). The experiment consists of a composite beam with embedded shape memory alloy wires, HP Programmable voltage/ current amplifier, laser range sensor, and a dSpace data acquisition and real time control system.
- Shape Control of Inflatable Structure Using Piezo-Film Actuator: There is great interest in DoD to use inflatable structures on future spacecraft to reduce spacecraft mass and launch cost and shape control of these large and flexible structures is a critical problem. This experiment is used to study the shape control of inflatable structures using piezo-film actuators (Figure 8). Analytical models are also developed using NASTRAN to predict the shape deformation as a function of actuator voltage. Research in this area is done in cooperation with Research Assistant Professor Ramesh Kolar, Department of Aeronautics and Astronautics.

This laboratory has also been used extensively by students for their thesis work resulting in two Ph.D., two Engineers, and eleven M.S. theses. Twenty technical papers in refereed journals and conference proceedings have resulted from the research conducted in this lab.

Several novel techniques have been developed. Bang and Agrawal developed a generalized second order compensator design for vibration control of flexible structures. Agrawal and LT Ronald Strong, USNR (M.S. Astronautical Engineering, December 1994)

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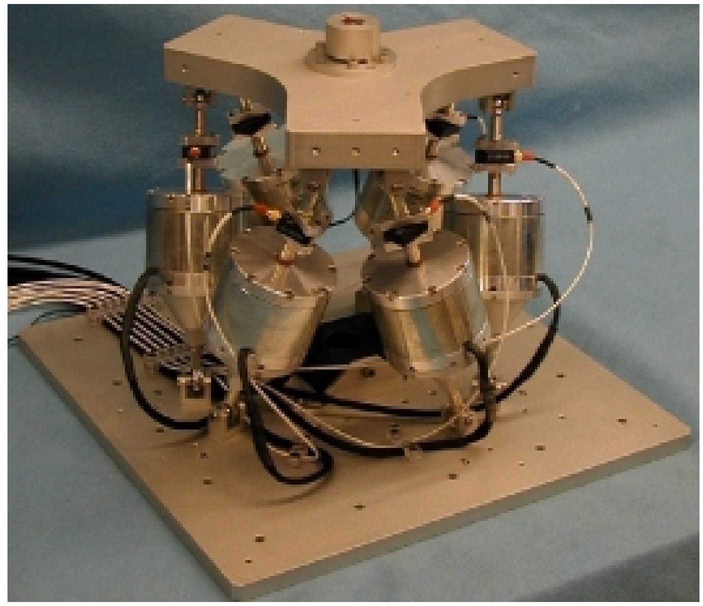

Figure 6. Positioning Hexapod.

Figure 7. Shape Control of a Honeycomb Beam.

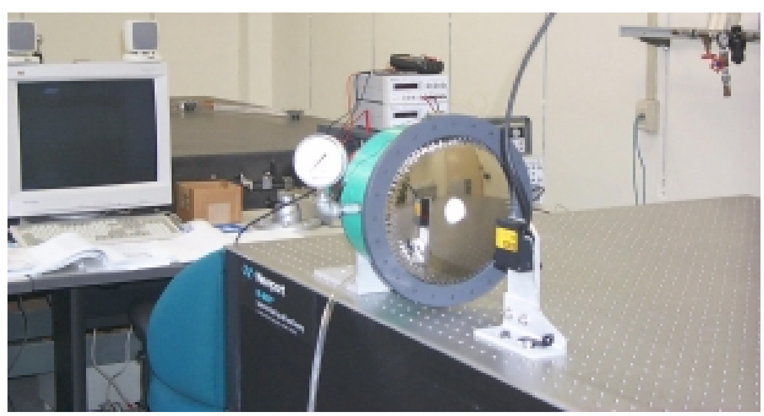

Figure 8. Shape Control of Inflatable Structure.

SCHEDULING AND DISTRIBUTING INTRA-THEATRE WARTIME PETROLEUM, OIL AND LUBRICANTS (POL) REQUIREMENTS

LCDR Joseph D. Noble, United States Navy
Master of Science in Operations Research-December 2000
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Second Reader: Distinguished Professor David A. Schrady,
Department of Operations Research

The Commander-in-Chief, United States Pacific Command (USCINCPAC) Joint Petroleum Office (JPO) oversees the storage and distribution of all petroleum products in the Pacific Theater. JPO planners use the decision support system described in this thesis to help determine if intra-theater wartime petroleum requirements can be satisfied for simulated or operational scenarios. Prior to the work presented in this thesis, JPO performed such analyses manually. The system uses optimization models to produce delivery plans and dispatch schedules for daily shipments of three fuel types via five different transportation modes (pipelines, tankers, barges, railcars, and trucks) amongst fifteen Defense Fuel Support Points (DFSPs). The system uses a spreadsheet interface to import data and to report results, such as fuel inventories and shortages across the distribution network, in tabular and graphical form. Dispatch schedules produced by the system provide detailed schedules for individual transportation assets and test the capacity assumptions employed in the delivery planning model. The USCINCPAC JPO used this system during two recent exercises, simulating wartime operating conditions and environment at the command level; for both exercises the system enabled JPO planners to perform rapid assessments of intra-theater fuel distribution capabilities and quickly validate the feasibility of intra-theater fuel distribution alternatives.

LCDR Noble was awarded the Joint Service Achievement Medal for his thesis contribution. The award citation reads, “Lieutenant Commander Joseph D. Noble, United States Navy, distinguished himself by exceptionally meritorious achievement through the development and successful implementation of the Japan Petroleum Distribution Model during exercise ULCHI FOCUS LENS 2000, from 21 August to 31 August 2000. This model was used by the Logistics, Engineering and Security Assistance Directorate’s Joint Petroleum Office to map fuel flow in Japan and identify fuels shortfalls at United States Department of Defense installations in Japan. During ULCHI FOCUS LENS 2000, the Japan Petroleum Distribution Model provided USPACOM senior leadership, through a series of graphs and reports, a near ‘real-time’ assessment of fuels capabilities at military airfields and installations throughout Japan. This first-ever capability for USPACOM will continue to prove invaluable as a planning tool for use in crisis or contingency. USPACOM senior leadership now has the capability to access ‘what if?’ fuels support questions in near real-time in our most challenging fuels support environment. Through his distinctive accomplishments, Lieutenant Commander Noble reflected credit upon himself, the United States Navy, and the Department of Defense.”

LCDR Noble is also the recipient of the Monterey Council Navy Leave Award for Highest Academic Achievement and the Chief of Naval Operations Award for Excellence in Operations Research.

THE EUROPEAN UNION’S BARCELONA PROCESS AND MEDITERRANEAN SECURITY

Major Richard E. Myrick, United States Marine Corps
Master of Arts in National Security Affairs-December 2000
Advisor: Professor David S. Yost,
Department of National Security Affairs
Second Reader: Senior Lecturer Tjarck Roessler,
Department of National Security Affairs

This thesis examines the Barcelona Process, a European Union initiative launched in 1995 with the goal of building an Euro-Mediterranean Partnership. The Barcelona Process links twelve countries of the southern littoral of the Mediterranean Sea with the European Union. The participants have three goals: shared prosperity, enhanced cultural exchanges, and political stability. This thesis investigates the European Union’s objectives in pursuing this process. Three possible motivations are analyzed: promoting prosperity and democracy, expanding a European Union-led trade bloc, or containing instability. The available evidence provides more support for the latter two motivations than the first. This thesis also investigates the North-South divide within the European Union itself, the influence of NATO and the United States, and possible solutions in view of the difficulties encountered thus far in pursuing the initiative’s goals. (Major Myrick is the recipient of the United States Naval Institute Award.)

COST-ATTRIBUTE ANALYSIS OF RESTRUCTURING H-60R/S FLEET REPLACEMENT SQUADRONS

LT Julia M. Lopez, United States Navy
Master of Science in Operations Research-December 2000
Advisor: LCDR Timothy P. Anderson, USN,
Department of Operations Research
Second Reader: Professor Richard E. Rosenthal,
Department of Operations Research

The U.S. Navy helicopter community will soon experience an unprecedented transformation; one that will see a massive shift in the identity of the community and in its fleet operations. In accordance with the Helicopter Master Plan (HMP), two new airframes, the SH-60R and CH-60S, will replace the existing helicopter inventory. This thesis develops the optimal way to structure the Fleet Replacement Squadrons (FRSs), specifying the location of the various FRSs and other training necessities. Four organizational options for restructuring the FRSs are considered: two separate airframe specific FRSs per coast, one combined FRS per coast, one FRS per airframe, and one single site combined FRS. Two different training plans are considered with each option. These training plans will consider whether or not to consolidate those portions of the syllabus common to both airframes. Training, maintenance, and support cost data are determined through the use of VAMOSC data and historical annual training requirements. A thorough attribute analysis of the different alternatives is performed. Using standard economic analysis techniques, multi-attribute decision theory is applied to enable a commander to choose the best option for FRS restructuring. When cost attributes are varied, the best alternative is to have two separate FRSs in NAS North Island, and two separate FRSs in NAS Jacksonville/Mayport. (LT Lopez is the recipient of the Military Operations Research Stephen A. Tisdale Graduate Research Award.)

A RETIREMENT PLANNING MODEL USING MONTE CARLO SIMULATION

LCDR Peter E. Hanlon, United States Navy
Master of Science in Management-December 2000
Advisors: Professor Shu Liao and Senior Lecturer Don Summers, Department of Systems Management

Uncertainty exists in retirement planning. The purpose of this thesis was to develop a stochastic retirement planning model to aid military personnel and decision/policymakers in evaluating retirement planning issues from a probabilistic perspective. The stochastic model developed differs from the ubiquitous retirement planning calculators available from many financial institutions and at many finance-related websites in that it accounts for the effects of uncertainty surrounding inflation and investment rates of return during one's investing "lifetime" by using Monte Carlo simulation techniques. The major components of the model are an input/output worksheet, a fund accumulation worksheet, a fund withdrawal worksheet, a probability distribution worksheet, and a pay table lookup worksheet. After completing 17 inputs and running a simulation, a user is able to determine the probability of achieving a specific amount of retirement savings as well as the probability associated with how many years the retirement savings, supplemented by military retirement benefits and Social Security, may last. The information gained by using the model allows military personnel to evaluate their current retirement plans and make necessary adjustments. Additionally, the model allows decision/policy makers to evaluate specific military retirement issues in order to determine how changes may affect service members. (LCDR Hanlon is the recipient of the American Society of Military Comptrollers Award for Excellence in Research.)

PRODUCTION OF ULTRA-FINE GRAINS AND EVOLUTION OF GRAIN BOUNDARIES DURING SEVERE PLASTIC DEFORMATION OF ALUMINUM AND ITS ALLOYS

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Master of Science in Materials Science and Engineering–December 2000
Advisor: Professor Terry R. McNelley,
Department of Mechanical Engineering

Equal channel-angular pressing (ECAP) is a recently developed method for deformation processing of material that can produce an ultra-fine grain structure in bulk material through severe plastic deformation. This study will present results on microstructural evolution during repetitive ECAP of pure aluminum. The principal method of data collection was Orientation Imaging Microscopy (OIM). The results of the study indicate that, after one ECAP pass, the structure is inhomogeneous and anisotropic, and consists mostly of

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STUDENTS FELLOWSHIPS AWARDED BY THE SPACE AND NAVAL WARFARE SYSTEMS CENTER-SAN DIEGO

The Space and Naval Warfare Systems Center-San Diego (SSC-SD) sponsors a Research Fellowship Program at the Naval Postgraduate School (NPS). The program was instituted to promote NPS' partnership with SSC-SD, address SSC-SD's research focus areas, lay the groundwork for future technical and project management assignments, and foster long-term professional associations with SSC-SD's technical personnel and management. To date, there have been 38 fellowships awarded to NPS students. The fellowship includes a $10,000 award to support the student's thesis research. The most recent recipients are LT Todd P. Erhardt, USN, Maj Jorge E. Lizzaralde, USMC, CPT Brian Lyttle, USA, Maj Joseph A. Matos, USMC, Capt Keith E. Shaffer, USMC, LT Melvin K. Yokoyama, Jr., USN, and CAPT Paul Young, USN.

LT Erhardt and CPT Lyttle will be pursuing a joint thesis project on "Providing Interoperability Between Legacy Systems." Their thesis advisor is Professor Valdis Berzins of the Department of Computer Science. LT Erhardt and CPT Lyttle are pursuing the Master of Science in Computer Science.

Maj Lizzaralde is pursuing the Master of Science in Information Systems Technology. He will be working with Lecturer Dan Warren, Department of Computer Science, on "Intrusion Detection Systems Requirements Analysis: An Evaluation of the Navy and Marine Corps' Current Use of COTS (Commercial-off-the-Shelf) IDS (Intrusion Detection Systems)."

Major Matos, pursuing the Master of Science in Systems Technology, will be working with Lecturer Dan Warren on the "Remote Access Vulnerabilities Associated with TimeStep Virtual Private Networks."

Capt Shaffer is working with Professor Tri Ha of the Department of Electrical and Computer Engineering. Pursuing the Master of Science in Systems Technology, his research topic will focus on the "Evaluation of Wireless Local Area Network Signal Transmission Vulnerabilities."

LT Yokohama is also working with Professor Tri Ha and is pursuing the Master of Science in Systems Engineering. His thesis research will focus on "Wireless Local Area Network Exploitation."

CAPT Young is working on his Ph.D. in Software Engineering with Professor Luqi, Director of the Software Engineering Automation Center and a member of the Department of Computer Science. His dissertation topic is "Integration of Heterogeneous Software Systems Through Computer-Aided Resolution of Data Representation Differences."

NPS OR DOCTORAL DISSERTATION SELECTED AS FINALIST FOR 2000 DANTZIG PRIZE

The September 1998 OR dissertation by LtCol Kirk Yost, USAF, titled "Solution of Large-Scale Allocation Problems with Partially-Observable Outcomes" has been honored as a finalist for the 2000 Dantzig Prize. The Dantzig prize honors the best international English language dissertation publication in Operations Research. This work, advised by Professor Alan Washburn of the Department of Operations Research, is motivated by sortie planning and experience from Desert Storm, where battle damage assessment with remote sensing is subject to error and deception, thus complicating planning for restrikes. Selection as one of the handful of finalists (with others from Stanford, University of Illinois, and Wharton) is especially noteworthy because the depth of the new theory and excellence of exposition more than compensate for the narrow focus of the motivating military application. Dr. Yost is now optimizing decision support for the Joint Staff.

LtCol Yost is not the only recent OR dissertation selected as a finalist for this prestigious award: The June 1997 OR dissertation by LtCol Steven F. Baker, USAF, titled "A Cascade Approach for Staircase Linear Programs with an Application to Air Force Mobility Optimization" was a finalist for the 1998 Dantzig Prize.

ULTRA-FINE GRAINS, *continued from page 19*

deformation-induced features. After repetitive ECAP, the aluminum material exhibited a homogeneous grain size but retained an anisotropic character to the microstructure. After twelve ECAP passes the microstructure consisted mainly of fine grains surrounded by high-angle boundaries but an appreciable fraction of low-angle boundaries remained. This microstructure thus comprises a mixture of deformation-induced and recrystallization features. Further results were also obtained documenting the existence of deformation banding in this material as well as in a rolled aluminum alloy. This phenomenon may be general in nature and associated with severe plastic deformation in aluminum and its alloys. (LT Swisher is the recipient of the Naval Sea Systems Command Award in Naval/Mechanical Engineering.)

AGREEMENT RENEWED TO CONTINUE SUPPORT OF THE TOTAL SHIP SYSTEMS ENGINEERING PROGRAM AT NPS

A Memorandum of Agreement has recently been signed by RADM David R. Ellison, USN, Superintendent of the Naval Postgraduate School, and RADM George R. Yount, USN, Deputy Commander for Integrated Warfare Systems at the Naval Sea Systems Command. The purpose of the agreement is to continue the support of the Total Ship Systems Engineering (TSSE) Program at the Naval Postgraduate School and to provide a mechanism for further development of the program by NAVSEA and NPS. The objectives of the TSSE program are to:

- Develop for U. S. Naval Officers a program in the interdisciplinary area of Total Ship Systems Engineering, which complements and enriches their accredited degree programs. This includes the necessary engineering and physical sciences, classical engineering and computer-aided design tools, and systems engineering methodologies which will address classical Hull, Mechanical & Electrical (HM&E) and Combat Systems subject matter in a Total Ship context.
- Encourage research into Total Ship Systems Engineering problems and processes. This includes faculty participation in Navy TSSE activities, student experience tours involving TSSE and TSSE research projects and theses.
- Support NAVSEA in its responsibilities to conceive and explore future ship and ship system designs and innovations by coordinating the TSSE student capstone design project with NAVSEA, by encouragement of NPS student thesis research and by involvement of TSSE faculty members in NAVSEA future ship explorations, as permitted by their teaching responsibilities.

The agreement also establishes two NAVSEA TSEE Chair Professorships at NPS, one with significant ship design and HM&E expertise and one with similar expertise in Navy combat systems.

LETTER OF INTENT ESTABLISHES NORTHROP GRUMMAN PROFESSORSHIP AT NPS

A Letter of Intent (LOI) formalized an agreement between the Naval Postgraduate School Foundation, Inc. (NPSFI), Northrop Grumman Corporation (NGC), and the Naval Postgraduate School (NPS) for the establishment and support of a Northrop Grumman (NG) Professorship of Systems Engineering and Integration (SEI) at the Naval Postgraduate School.

In recognition of its commitment to national security and of the importance of assisting in the technical education of United States and foreign military officers, Northrop Grumman has agreed to provide funding to the NPSFI to establish and fund the Northrop Grumman Professorship of Systems Engineering and Integration at NPS.

Funding received from Northrop Grumman will be used to support educational and research programs in Systems Engineering and Integration, and to provide an annual Northrop Grumman Award for Excellence in Systems Engineering and Integration.

COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT CONTINUES COLLABORATION WITH TRW

A follow-on Cooperative Research and Development Agreement (CRADA) was recently signed with TRW Inc. to continue the relationship for joint research, experimentation and technology development activities. These activities seek solutions to complex information technology and intelligence systems problems to enhance the effectiveness of the military services. The NPS faculty's expertise in directed scientific research, and the NPS student's operational background and academic learning objectives, will be applied together with TRW's expertise in information and signal characterization, collection, processing, and fusion-focused concept implementation to solve such problems.

FOURTH NASA CHAIR PROFESSOR JOINS NPS

Dr. Stephen A. (Tony) Whitmore joins the Naval Postgraduate School as the fourth Michael J. Smith Space Systems Chair Professor. Dr. Whitmore brings a wealth of experience from his current position as a Senior Research Engineer at NASA Dryden Flight Research Center (DFRC).

Before coming to the NPS, Dr. Whitmore served as the vehicle dynamics group head at DFRC and for the past year has acted as the chief engineer on the NASA X-37/X-40 Access-to-Space programs. His areas of expertise include experimental aerodynamics, parameter identification, and digital filtering.

In his role as the "NASA" Chair, Dr. Whitmore will teach, advise students, and act as a liaison between NASA and NPS on matters pertaining to teaching and research in the space systems arena. The Chair professorship was created in 1995 to honor the memory of astronaut CAPT Michael J. Smith, USN, an alumnus of NPS.

NPS DUDLEY KNOX LIBRARY HOSTS 44th MILITARY LIBRARIANS WORKSHOP

Defense agencies are changing and being redesigned to respond to the new threats of today in the effort to increase peacekeeping and humanitarian roles, the revolution in military and business affairs, and rapid changes in the systems of information storage and delivery. Military libraries must anticipate and respond as rapidly to these changes in mission and information delivery systems as they happen, so that they may provide the information necessary for commands to accomplish their missions.

The 44th Military Librarians Workshop, hosted recently by the Dudley Knox Library at the Naval Postgraduate School, presented an opportunity for approximately 175 military librarians and other information professionals from commands all over the world to engage in discussions of these issues. The workshop promoted participants awareness of the tools and approaches used by other commands to solve problems caused by these rapid changes, and helped libraries and librarians to respond quickly and effectively to the rapid change in information service and delivery systems, said Dr. Maxine Reneker, Associate Provost for Library and Information Resources at the Naval Postgraduate School.

The conferences sessions emphasized examination of library and information services in new ways. Library consultants Barbara Robinson and Maureen Sullivan challenged participants to examine what business we are in, who are our customers, and what competencies will we need in the future to serve them? In the opening presentation, Maxine Reneker of NPS highlighted the theme, Steer by the Stars, Not by the Wake, emphasizing the differences between the traditional library, a facility containing all the relevant knowledge needed to support its user in one location, with today's library that contains resources in many formats, including electronic and web-based information. Our present day military libraries are structured to support users in many locations, with resources in many formats, wherever the user is electronically accessible via the desktop, laptop, or any other information device. Reneker predicts that future libraries will emphasize the processes and human expertise that support information services, rather than be constrained by physical location. The norm will be the acquisition of information in digital format, rather than in print format. Using a new model of library service proposed by Winkworth, et. al., she sees the future library of first resort is less a store of information resources aspiring to self-sufficiency and more a system of procedures for accessing information resources dispersed across networks of cooperation peer-libraries, the shell-structure of processes

During the 44th Military Librarians Workshop hosted by the Naval Postgraduate School's Dudley Knox Library, Carol Ramkey, Director, Marine Corps University Library, describes the partnerships among the nine libraries in the Library Working Group of the Military Education Coordination Conference and its linked catalog, MERLN.

and human expertise, and not a shelter for resources and users. The NPS library future scenario focuses on integrated, personalized delivery information normally delivered digitally to ubiquitous ports of access worldwide and scholarly reward system, which will support contributions to information access. The role of librarians and information specialists: develop and support new information tools, assess information landscape, and enrich information environment, said Reneker.

Associate Professor John Arquilla of the Information Warfare Academic Group, in a luncheon talk on "The Future of Conflict," told the librarians that everything we believed about national security affairs during the cold war has basically come undone. Dr. Arquilla spoke of the growing disruptive and destructive power of the small formation. "Big armies with heavy tanks and big artillery... all the things we have relied upon are in a state of flux," said Arquilla. Because of the power of connectivity of other small units with each other and other assets, such as aircraft, or cruise missiles, or land attack missiles, the small units can call upon tremendous fire to support their operations. He cited the battles of the Chechen rebels with the Russians six years ago, noting that the fact this "rag tag force" was able to defeat what we thought was one of the best militaries in the world is an

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TECHNOLOGY REVIEW AND UPDATE

The Naval Postgraduate School will offer the 18th Technology Review and Update Course for Technical Personnel the week of 23-27 April 2001. **Professor Rudolf Panholzer**, Dean of Science and Engineering and Chair of the Space Systems Academic Group, coordinates the course.

The success and popularity of this short course is ensured by recruiting outstanding experts from industry, academia and the government and by constantly finetuning the contents. The course is intended for military and civilian technical personnel interested in refreshing and updating their technical knowledge. The course provides an excellent overview and stresses the more practical aspects of the topics listed. The course is presented at the unclassified level. Sessions will cover:

- Internet Security - Opportunity or Oxymoron
- Electro-Optical and Infrared Systems
- Micro Electro-Mechanical Systems (MEMS)
- Optical Sensing Technology
- Military Satellite Communications Technologies
- Satellite Communication Technologies and Trends
- Computational Intelligence

Registration information and program details can be obtained at www.sp.nps.navy.mil/trau or by calling (831) 656-5041.

CLASSIFIED ADVANCED TECHNOLOGY UPDATE SHORT COURSE

The U.S. Naval Postgraduate School will host the Third Annual Classified Advanced Technology Update (CATU) Short Course the week of 23-27 July 2001. The CATU is a week-long course facilitated by NPS **Professor Herschel Loomis** of the Department of Electrical and Computer Engineering, and organized and managed by **Ms. Rita Painter**, the NPS/SPAWARSYSCEN Cryptologic Program Manager. With the overwhelming success of the two previous CATUs, participation is expected to reach 250, in addition to the 35 guest speakers.

The CATU is intended for TOP SECRET/SCI-cleared military and civilian technical personnel who are interested in refreshing and updating their knowledge in the areas of advanced technologies that support the mission of the Department of Defense. Technical subjects covered include specific topics in Cryptology, Information Operations, Overhead Reconnaissance, Digital Signal Processing, Communications, Low Probability of Intercept, and Geolocation. Guest lecturers will be selected based upon their renowned work and recognized subject matter knowledge in their area of expertise.

Last year, Dr. William Perry, the former Secretary of Defense, and now a professor at Stanford University's Institute for International Security, was the keynote speaker. His presentation, "The Role of Technology in National Security," provided insight into the history of technology and how it has evolved in national security applications.

Registration information and program details can be obtained by calling (831)656-2110/2148.

2K INFORMATION WARFARE WORKSHOP FOCUSED ON CYBER SECURITY

The 2000 Information Warfare (IW) Workshop, sponsored by the Department of Energy, Office of Energy Intelligence, and hosted by the U.S. Naval Postgraduate School (NPS), was held on 31 October-2 November 2000. This was the fifth annual IW Workshop. **CAPT James R. Powell, USN**, Chair of the Information Warfare Academic Group, and **Ms. Rita Painter**, NPS/SPAWAR Systems Center-San Diego Cryptologic Program Coordinator, coordinated efforts to make this event another successful experience for DoD attendees, who have come to expect the best at NPS.

This years workshop focused on Cyber Security and included discussions on threats, solutions, coordination, community research needs, and collection requirements. The workshop followed a format of one day of briefings, to include welcoming remarks from NPS Superintendent, **RADM David R.Ellison, USN**, and two subsequent days of IW wargaming and discussions.

As was the case with the previous IW workshops, this event was conducted at the Top Secret/SCI level. Approximately 80 DoD representatives of various intelligence communities/functions/offices of the federal government, military services, and contractor elements were in attendance. NPS faculty and students, with the requisite clearance, were invited to attend and actively participate.

Workshops such as this provide the participants the opportunity to collectively examine, further define, and systematically develop new collection strategies for IW exploitation and control. Hosting the IW Workshops at NPS provides the participants a non-attributive venue for the collegial exchange of ideas and concepts and the investigation of required defensive and offensive actions for securing and maintaining information dominance in the 21st Century. The 6th Annual IW Workshop at NPS has been tentatively scheduled for November 2001.

NPS DUDLEY KNOX LIBRARY HOSTS WORKSHOP, *continued from page 22*

example of the power of the small band of between 12 and 20 fighters. He believes there is far more to learn about the future of war from what went on in the Trans Caucasus region than in the Gulf War. Arquilla emphasized that the librarians job is about structuring information; he believes there is only meaning in data if we can structure it in useful ways: then data becomes knowledge and we turn it into wisdom and insight.

Professsor Mike Zyda, Chair of the Modeling, Virtual Environments, and Simulation (MOVES) Academic Group, discussed the 1997 National Research Council report outlining a joint research agenda for defense and entertainment modeling and simulation. A number of research laboratories have developed a joint entertainment / Virtual Reality or entertainment / defense or entertainment / NASA focus. The Naval Postgraduate School MOVES Program is the largest modeling, virtual environments and simulation academic program. Computer-based modeling and simulation in DoD span a wide range of types and complexity, from physics-equation models of particle motion to behavioral representations of military systems and personnel in combat scenarios. Professor Zyda described different NPS projects in modeling and simulation.

The Department of the Navy Chief Information Office has developed the Next Generation Library, and NPS is in the process of developing an NPS Knowledge Portal, using software that learns user preferences and suggests to the user information that he or she may be interested in using. The Next Generation Library and the NPS Knowledge Portal are designed to improve the management of knowledge and information and overcome some of the barriers to timely and appropriate information flow. Librarian of the Navy Joan Buntzen, described the two Naval projects, which include capabilities to support connections to other users, visualization of retrieval results, training and curricula support, access to scholarly journals, e-business, Information Technology news and information, relevant web sites, virtual librarians, business news and information, electronic documents, lessons learned, communities of interest, and a peer and expertise finder. The NPS Knowledge Portals goal is to minimize the time needed to locate and share relevant information.

With the explosion in information in electronic databases and other electronic resources, the ways of describing these information resources are rapidly changing. The workshop offered by Greta de Groat of Stanford University addressed some of these rule changes and talked about how libraries can use the rules to describe the information resources in electronic format, such as electronic books, journals, and databases, that they offer to the military library community and NPS. Aggregator databases are databases of electronic information that provide information from more than one publisher, thus they are aggregated from a variety of publishers. Some of the complex issues relate to such things as who owns the intellectual property rights to the information, and how should it be described. Greta Marlatt, of the NPS Library, gave a workshop on "Finding Defense Information on the Net," helping participants utilize the over 16,000 search engines and directories to locate relevant, timely, and authoritative defense-related materials.

The presentations on distributed education were important because as librarians we must provide information resources, and assistance in using them, to students wherever they are, said Reneker. Many military commands are instructing users at sites beyond their resident campuses, and we are just now learning the differences in how students learn in web-based and synchronous distributed education courses and what we need to do as libraries in assisting that learning. These presentations were given by Jim Bradley, U.S. Army Headquarters Training and Doctrine Command, Bohdan Kohutiak, Director, U.S. Army War College Library, Dr. Laseter of Air University Library, and Ann Parham, Librarian of the Army.

Reneker said that NPS was praised for raising the bar in both the conference arrangements and substantive material presented. The NPS Dudley Knox Library is one of the leaders among the defense community libraries in identifying and providing defense-related information. As you can surmise, we use a nautical analogy, Steer by the Stars, Not by the Wake, to describe the rapidly changing methods of delivering information, such as web-based instruction, new information tools such as electronic books and journals, information portals, and web pages, said Reneker. We have new roles in instructing users in the evaluation and use of these tools, and to do this, we must learn them ourselves. In our world, the market cycle of these products is 18 months before many of them change again. Therefore, we must continuously learn how to effectively use them and instruct others in their use. Most of the presentations at the Military Librarian Workshop were videotaped and are available for viewing over the Internet at http://web.nps.navy.mil/~library/mlw2000.htm.

FACULTY NEWS

NPS WINS NRO DIRECTOR'S INNOVATIVE INITIATIVE AWARD

A Naval Postgraduate School (NPS) and Air Force Research Lab (AFRL) team headed by **Professor Brij Agrawal** of the Department of Aeronautics and Astronautics is the recipient of a very competitive and prestigious National Reconnaissance Office (NRO) Director's Innovative Initiative (DII) award. The title of the successful project is "Bifocal Relay Mirror Technology Development." The award is for $340K with NPS as prime contractor and AFRL as subcontractor for their expertise in optics.

The bifocal relay mirror spacecraft system is composed of two optically coupled telescopes used to redirect the laser light from ground-based, aircraft-based or spacecraft-based lasers to distant points on the earth or in space for a variety of non-weapon, force enhancement missions. The missions include camouflage detection and penetration, chemical warfare agent detection and identification, illuminator for nighttime/active imaging, laser fence for aircraft detection, and underground structure detection. The receiver telescope captures the incoming energy from a laser transmitter system while a separate transmitter telescope directs the laser beam at the desired target. Each telescope requires target acquisition and tracking systems with the transmitter side requiring the added capability of tracking uncooperative terrestrial-based targets. At NPS, a preliminary design of the spacecraft was completed by students in course AA 4871, Spacecraft Design II in the summer 2000. This effort identified the need to develop several new unique technologies pushing the boundaries of technologies for this mission in the areas of fine beam/target acquisition, tracking and pointing (ATP), beam control optics and the integrated beam/spacecraft control. The proposal was based on this technology development.

The NRO DII Program was established by the Director, NRO, Mr. Keith Hall, in 1998. NRO has stated three principal objectives: Provide a risk tolerant environment to invest in cutting edge technologies and high payoff concepts relevant to the NRO's mission to "Revolutionize Global Reconnaissance," foster innovation and provide seed funding to push the boundaries of the technology to dramatically improve our nation's satellite reconnaissance capabilities, and present an opportunity not traditionally associated with NRO to participate in building the NRO of the 21st century. Since the inception, more than 1400 proposals have been submitted to the program and 120 have been selected for funding, an award ratio of 1 to 10. It is open to government laboratories, industry and universities. DII projects are awarded to determine the technological feasibility of high technological risk, potentially high payoff ideas. As such, contract awards are limited in scope to not more than 9 months in duration with $350K maximum funding. The selection criteria were potential contributions to the NRO, innovativeness of the proposed effort, and uniqueness.

AERONAUTICS AND ASTRONAUTICS

B. Agrawal and **H.J. Chen**, "Active Vibration Isolation on Spacecraft Using Smart Struts," IAF-00.I.4.05, 51st International Astronautical Congress, Rio de Janeiro, Brazil, 2-6 October 2000.

Prof. B. Agrawal chaired a session on Spacecraft Attitude Control, 51st International Astronautical Congress, Rio de Janeiro, Brazil, 2-6 October 2000.

F. Bernelli-Zazzera, M. Romano, and **B. Agrawal**, "Experiments on Tracking Control of a Flexible Space Manipulators," IAF-00-A.3.05, International Astronautical Congress, Rio de Janeiro, Brazil, 2-6 October 2000.

O. Biblarz and G.P. Sutton, *Rocket Propulsion Elements*, 7th ed., January 2001.

C. Brophy, "Liquid JP-10/Air Detonations for Pulse-Detonation Engine Applications," *Control of Detonation Processes*, ELEX-KM Publishers, January 2001.

K.D. Jones, S.J. Duggan, and **M.F. Platzer**, "Flapping Wing Propulsion for a Micro-Air-Vehicle," AIAA Paper 2001-0126, 39th Aerospace Sciences Meeting, Reno, NV, 8-11 January 2001.

G. Song, **B. Kelly**, and **B. Agrawal**, "Active Position Control of a Shape Memory Alloy Wire Actuated Composite Beam," *Journal of Smart Materials and Structures*, Vol. 9, 2000.

C. Tillier and **B. Agrawal**, "Yaw Steering for LEO Satellite Using Any Two of Three Reaction Wheels," IAF-00-A.2.01, 51st International Astronautical Congress, Rio de Janeiro, Brazil, 2-6 October 2000.

S. Weber and **M.F. Platzer**, "Computational Simulation of Dynamic Stall of the NLR 7301 Airfoil," *Journal of Fluids and Structures*, Vol. 14, 2000.

S. Weber and **M.F. Platzer**, "A Navier-Stokes Analysis of the Stall Flutter Characteristics of the Buffum Cascade," *Journal of Turbomachinery*, Vol. 122, October 2000.

COMPUTER SCIENCE

S. Balmer and **C.E. Irvine**, "Analysis of Terminal Server Architectures for

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Thin Clients in a High Assurance Network," 23rd National Information Systems Security Conference, Baltimore, MD, 18-21 October 2000 (Best Paper Award).

C.E. Irvine and T. Levin, "Quality of Security Service," 23rd National Information Systems Security Conference, Baltimore, MD, 18-21 October 2000.

C.E. Irvine, "An Argument for Academic Research in Information Security," 23rd National Information Systems Conference, Baltimore, MD, 18-21 October 2000.

E. Spyropoulou, T. Levin, and C.E. Irvine, "Calculating Costs for Quality of Security Service," 16th Computer Security Applications Conference, New Orleans, LA, December 2000.

COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, AND INTELLIGENCE

A. Bordetsky and G. Mark, "Memory-Based Feedback Controls to Support Groupware Coordination," *Information Systems Research*, Vol. 11, 4, 2000.

A. Bordetsky, "Adaptive QoS Management via Multiple Collaborative Agents," *Agent Technology for Communications Infrastructure*, Wiley and Sons, 2000.

A. Bordetsky, "Celestial Data Routing Network," *Proceedings of Small Payloads in Space*, 45th International Symposium on Optical Science and Technology, August 2000.

DEFENSE RESOURCE MANAGEMENT INSTITUTE

D.I. Angelis, "Capturing the Option Value of R&D," *Research-Technology Management*, Vol. 43, No. 4, 2000.

D.I. Angelis, "Activity Based Management in Government Organizations," AFMC/DR Reserve Conference, November 2000.

Prof. D.I. Angelis has joined the Core Group of the Consortium for Advanced Manufacturing International Project Management Group.

J. Boex, J. Martinez-Vasquez, and R. McNab, "Multi-Year Budgeting : A Review of International Practices and Applications for Developing and Transnational Economies," *Public Budgeting and Finance*, Vol. 20, No. 2, Summer 2000.

Prof. P.C. Frederiksen has accepted a visiting Fellowship at the Asia Pacific Center for Security Studies, Senior Executive Course 01-1, Honolulu, HA, January through April 2001.

ELECTRICAL AND COMPUTER ENGINEERING

B. Barsanti, "Passive Target Tracking with Uncertain Sensor Positions," 34th Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, 29 October-1 November 2000.

W.U. Gillespie, J.P. Powers, and P.E. Pace, "Design and Experimental Evaluation of an Integrated Optical Sigma Delta Modulator for Digital Antennas," DARPA/MTO 2000 RF Lightwave Integrated Circuits Symposium, Cincinnati, OH, 16 October 2000.

R. Ives, "Lossless Compression of SAR Imagery Using a Multiple-Pass Gradient Adaptive Lattice Filter," 34th Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, 29 October-1 November 2000.

R. Janaswamy, *Radiowave Propagation and Smart Antennas for Wireless Communications*, Kluwer Academic Publishers, November 2000.

S. Mantis and R. Hippenstiel, "Time Difference of Arrival Estimation of Denoised Unequal SNR Communications Signals," 34th Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, 29 October-1 November 2000.

K. Shea, R. Ives, and M. Tummala, "Mobile Ad Hoc Network Routing Protocol Analysis and Its Application to a Programmable Modular Communication System," 34th Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, 29 October-1 November 2000.

METEOROLOGY

K. L. Davidson and P. A. Frederickson, "Influence of Ocean Waves on Near-surface Turbulence and Refraction Profiles," National Radio and Science Meeting (URSI) , 8-11 January 2001, University of Colorado, Boulder, CO.

P. A. Frederickson and K. L. Davidson, "Air-Sea Flux Measurements From a Buoy in a Coastal Ocean Region." Preprints, 14th Symposium on Boundary Layers and Turbulence, Aspen, CO, American Meteorological Society.

P. A. Frederickson and K. L. Davidson, "A Sensitivity and Convergence Analysis of a Bulk Air-Sea Flux Model." Preprints, 14th Symposium on Boundary Layers and Turbulence, Aspen, CO, American Meteorological Society.

P.A. Frederickson, K.L. Davidson, C.R. Zeisse, and C.S. Bendall, "Estimating the Refractive Index Structure Parameter Over the Ocean Using Bulk Methods," *Journal of Applied Meteorology, Vol. 39*, October 2000.

Prof. Q. Wang has been invited to serve on the American Meteorological Society (AMS) Committee on Boundary Layers and Turbulence. Her term will cover the 3-year period from January 31, 2001 to January 30, 2004.

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MODELING, VIRTUAL ENVIRONMENTS, AND SIMULATION

Prof. M. Zyda recently served on a National Research Council Committee that produced the report "Advanced Engineering Environments (AEE)." NASA Director Dan Goldin, in a letter to the committee, wrote "The team you assembled to conduct the study should be highly complimented. The AEE is extremely important to NASA and is the backbone of our Intelligent Synthesis Environment (ISE) Program."

NATIONAL SECURITY AFFAIRS

P. Lavoy, S. Sagan, and **J.J. Wirtz**, eds. *Planning the Unthinkable: How New Powers Will Use Nuclear, Chemical and Biological Weapons*, Cornell University Press, 2000.

R. Looney and **P. Frederiksen**, "The Effect of Declining Military Influence on Defense Budgets in Latin America," *Armed Forces and Society*, Spring 2000.

R. Looney, "Mexico," Lawrence Boudon, ed., *Handbook of Latin American Studies*, No. 57 Social Sciences, Austin University of Texas Press, 2000.

D. Porch, *Wars of Empire*, October 2000.

J.J. Wirtz, "The Battles of Saigon and Hue: Tet 1968," Military Operations in an Urban Environment: Lessons from the Past for Current Doctrine and Future Policy, Patton Museum, Ft. Knox, KY, September 2000.

J.J. Wirtz, "Revising the ABM Treaty: Seeking Strategic Stability in a World of Nuclear Danger," 68th Military Operations Research Society Symposium, USAF Academy, Colorado Springs, CO, June 2000.

J.J. Wirtz, "Counterproliferation, Conventional Counterforce and Nuclear War," *Journal of Strategic Studies*, Vol. 23, March 2000.

J.J. Wirtz, "Review of Harold A. Feiveson's: The Nuclear Turning Point," *Political Science Quarterly*, Vol. 115, Spring 2000.

J.J. Wirtz, "A Question of Culture," Review of Arthur Hulnick's Fixing the Spy Machine, *International Journal of Intelligence and Counterintelligence*, Vol. 13, Summer 2000.

J.J. Wirtz and R. Godson, "Strategic Denial and Deception," *International Journal of Intelligence and Counterintelligence*, Vol. 13, Winter 2000.

D.S. Yost, "The NATO Capabilities Gap and the European Union," *Survival*, Vol. 42, Winter 2000.

D.S. Yost, "Russia and Arms Control for Non-Strategic Nuclear Forces," Conference on Dealing with Non-Strategic Nuclear Weapons, Warrenton, VA, November 2000.

OPERATIONS RESEARCH

A.J. Ahumada and **W.K. Krebs**, "Models for Masking by Fixed-Pattern Chromatic Noise," Psychonomic Society of America Annual Meeting, New Orleans, LA, November 2000.

A.J. Ahumada and **W.K. Krebs**, "Masking by Fixed-Pattern Chromatic Noise," Optical Society of America Annual Meeting, Providence, RI, October 2000.

A.J. Ahumada and **W.K. Krebs**, "Masking in Color Images," *Proceedings of the SPIE-Human Vision and Electronic Imaging IV*, B.E. Rogowitz and T.N. Pappas, eds., Vol. 4299, Bellingham, WA, 2001.

K.J. Becker, **D.P. Gaver**, K.D. Glazebrook, **P.A. Jacobs**, and **S. Lawphongpanich**, "Allocation of Tasks to Specialized Processors: A Planning Approach," *European Journal of Operational Research*, Vol. 126, 2000.

S. Das and **W.K. Krebs**, "Sensor Fusion of Multi-Spectral Imagery," *Institution of Electrical Engineers: Electronic Letter*, 36, 2000.

W.K. Krebs, E.A. Essock, **S.E. Buttrey**, M.J. Sinai, and J.S. McCarley, "An Oblique Effect of Chromatic Gratings Measured by Color Mixture Thresholds," *Perception*, 8, 2000.

D. Olwell and **A. Sorrel**, "Warranty Calculations for Missiles With Only Current-Status Data, Using Bayesian

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During the period from 19 January through 3 March 2001, the Department of Meteorology is hosting a coastal field experiment in conjunction with the National Oceanic Atmospheric Agency (NOAA) Environmental Technology Laboratory (ETL). The field experiment is called the Pacific Landfalling Jets (PACJET) Experiment and is a follow-on to the much publicized California Landfalling Jets (CALJET) Experiment held in 1998. The Operations Center is being housed at NPS. Weather briefings are held each day in the Department of Meteorology's Synoptic Lab. Associate Professor Wendell Nuss and Research Assistant Professor Douglas Miller are directly involved with the experiment as collaborators. The hosting of this experiment is highly beneficial to Professors Nuss and Miller who regularly collaborate with National Weather Service personnel and NOAA ETL on various research efforts. The PACJET effort is particularly aimed at supporting operational weather forecasters within NOAA. Hosting the PACJET Operations Center provides a number of unique opportunities for NPS Meteorology students, faculty and staff: being able to directly interact with numerous NOAA and NWS scientists, being exposed first hand to the conduct of meteorological field work, having first-hand access to research datasets, being exposed to NWS operational forecasters that conduct the briefings, and having the opportunity to participate in data collection using the NOAA P-3 research aircraft.

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Methods," *Proceedings of the 2001 Reliability and Maintainability Symposium (RAMS)*, January 2001.

D. Olwell, "Reliability Leadership," *Proceedings of the 2001 Reliability and Maintainability Symposium (RAMS)*, January 2001.

S.M. Sanchez, "Beyond Selection: Why Is This System Best?" Fall 2000 INFORMS Meeting, San Antonio, TX.

S.M. Sanchez, "Robust Design: Seeking the Best of All Possible Worlds," *Proceedings of the 2000 Winter Simulation Conference*, J. Joines, R. Barton, and K. Kang, eds., Institute of Electrical and Electronics Engineers, Piscataway, NJ, 2000.

S.M. Sanchez, D. Ferrin, T. Ogazon, T. Sepulveda, and T. Ward, "Emerging Issues in Healthcare Simulation," *Proceedings of the 2000 Winter Simulation Conference*, J. Joines, R. Barton, and K. Kan, eds., Institute of Electrical and Electronics Engineers, Piscataway, NJ, 2000.

Prof. S.M. Sanchez is Acting Editor-In-Chief of *Naval Research Logistics* and the Simulation Area Editor for the *INFORMS Journal on Computers* in 2001.

D. Schrady, "Sea-Based Logistics and Lessons from the Falklands," International Symposium on Military Operations Research, Oxford, UK, August 2000.

D. Schrady, "Combat Logistics Command and Control for the Joint Forces Commander," Canadian Forces College, Toronto, Canada, October 2000.

K. Wood and J. Salmeron, "Solving Stochastic Network Interdiction Problems," Fall 2000 INFORMS Meeting, San Antonio, TX.

Associate Professor Robert F. Dell of the Department of Operations Research received a research grant from the Office of Naval Research Affordability Measurement and Prediction Program to develop theory for and applications of optimization-based decision support. Two immediate goals are long-range planning of ship, submarine, and aircraft procurement and retirement for U.S. Navy Chief of Naval Operations Assessment Division (N81), and modeling petroleum storage and distribution capabilities for USCINCPAC.

SYSTEMS MANAGEMENT

T. Baker, "Implementing Change and the Basic School Quandary," *Marine Corps Gazette*, October 2000.

B. Gates and M. Nissen, "Agent-Based Market Design for Navy Enlisted Personnel," Navy Manpower Research and Analysis Conference, Washington, DC, 2000.

J. A. Joines, R.R. Barton, K. Kang, and P.A. Fishwick, eds., *Proceedings of the 2000 Winter Simulation Conference*, Vols.1 and 2, 2000.

L. Jones, "International Public Management Trends and Implications for Russia," Russian Peoples' Friendship University, Moscow, Russia, September 2000.

Prof. K. Kang was the Program Chair for the 2000 Winter Simulation Conference held in Orlando, FL, 10-13 December 2000. He received the Distinguished Service Award from the Board of Directors during the conference.

L. Letendre and K.W. Thomas, "Managing Conflict in the Boardroom," Annual Corporate Governance Conference, National Association of Corporate Directors, Washington, DC, October 2000.

I. Lewis, "Third-Party Logistics: Leveraging Information Technology," *Journal of Business Logistics*, Vol. 21, 2000.

I. Lewis and D.B. Vellenga, "The Ocean Shipping Reform Act of 1998," *Transportation Journal*, Summer 2000.

S. Mehay, K. Gue, and Paul Hogan, "*The Recruiting Station Location Evaluation System (RLSES): A Summary Report*," NPS-SM-00-009, June 2000.

B. Naegle, "Educating the Future Acquisition Workforce," *The Army Acquisition Workforce Newsletter*, Fall 2000.

M. Nissen, and K. Sengupta, "An Experimental Approach to Understanding Human and Software Agent Performance Along the Supply Chain," Arizona Information Systems Research Workshop, Tucson, AZ, 2000.

K. Strayer, T. Hoivik, and S.P. Hocevar, "The Use of Advanced Warfighting Experiments to Support Acquisition Decisions," *Acquisition Review Quarterly*, Vol. 7, Fall 2000.

J. Suchan, "Creating and Communicating Distributed Learning Processes and Policies: A Case Study," Association of Business Communication Conference, Atlanta, GA, October 2000.

J. Suchan and G. Fann-Thomas, "Distributed Learning Research Issues and Propositions," Association of Business Communication Conference, Atlanta, GA, October 2000.

K.W. Thomas, "Unlocking the Mysteries of Intrinsic Motivation," *OD Practitioner*, Vol. 32, No. 4, 2000.

K.W. Thomas, "Intrinsic Motivation and How It Works," *Training*, Vol. 37, No. 10, October 2000.

K.W. Thomas, "Unlocking the Mysteries of Intrinsic Motivation in Self-Managing Workplaces," OD Network Annual Conference, Atlanta, GA, October 2000.

TIME CRITICAL STRIKE, *continued from page 5*

several images of the same scene at different portions of the optical spectrum. While the multispectral sensors provided valuable information for terrain mapping, it was clear that additional spectral resolution was necessary to accurately identify materials for both military and non-military applications. For that reason, a number of new sensors have been developed to produce highly resolved spectra on a pixel by pixel basis. The two best known are the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and the Hyperspectral Digital Imagery Collection Experiment (HYDICE), both developed by NASA. These two sensors collect over 200 spectral samples between 400 nm (blue end of the visible spectrum) to 2.2 microns (in the short-wave infrared region of the spectrum). Sensors with such fine spectral resolution are known as hyperspectral imagers (HSI), and experimental HSI sensors have been developed to work in all parts of the optical spectrum, including mid-wave IR (3-5 microns) and long-wave IR (8-12 microns).

Two projects currently under way at NPS involving HSI involve processing and display of spectral imagery. Associate Professor Richard C. Olsen, Department of Physics, and Capt J. Scott Tyo, USAF, Department of Electrical and Computer Engineering, in collaboration with several current and recent NPS students are exploring these problems. One of the principal difficulties associated with the use of HSI for time-critical strike is the rapid understanding of the huge amounts of data that make up a spectral image. A single AVIRIS or HYDICE image of a one square kilometer scene can take up more than 180 Mbytes of memory. Furthermore, AVIRIS and HYDICE collect information from portions of the spectrum not familiar to a human observer. Capt David Diersen, USMC, recently began to attack this problem with his thesis, "An Analysis of Display Strategies for HSI." Diersen's thesis focused on developing display strategies that are easy and rapid to implement that highlight the important aspects of a HSI scene in a manner that is readily interpretable to a human observer. For example, one might ask how could infrared information be incorporated into a color display while still keeping water blue and grass green? It might not always be possible to do so, but researchers at NPS are trying.

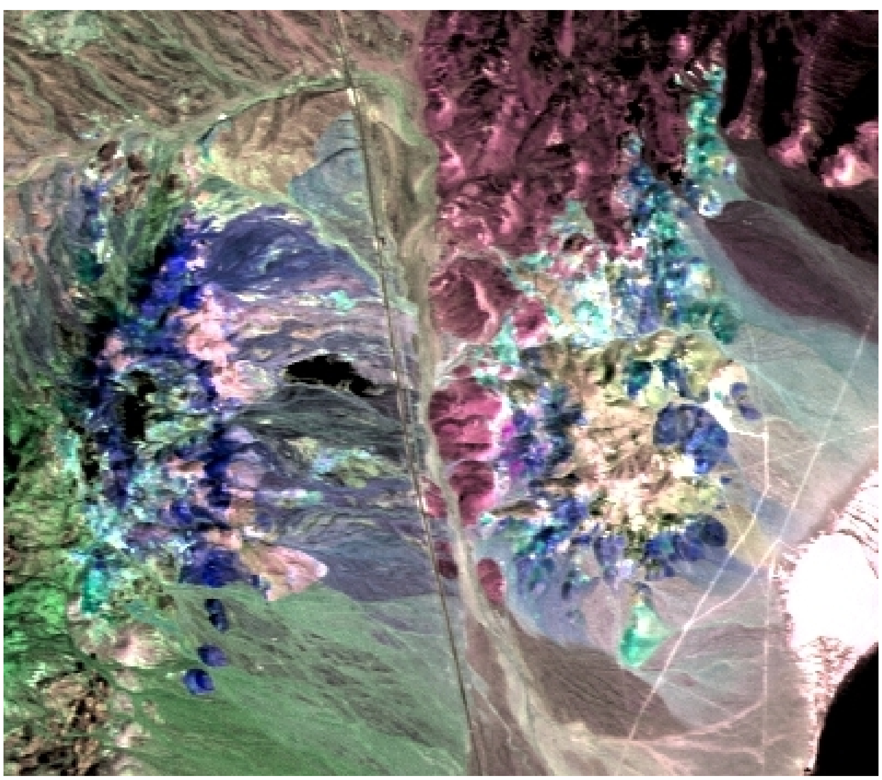

Figure 1. Image from mountainous terrain processed using a prototype display strategy developed by Capt Tyo.

Figure 1 shows an image from mountainous terrain that has been processed using a prototype display strategy developed by Tyo. In this image, different types of terrain can be identified as different hues in the final image, which is essential in making decision for time-critical strike.

A second important possibility for HSI is the autonomous detection and identification of various targets on the ground. For high-altitude or satellite-borne spectral sensors, the ability to automatically detect certain targets can greatly reduce the amount of data that must be sent down to the ground. A number of researchers around the world are developing algorithms to extract information from spectral imagery, many of which are statistically based. LT Joel Robertson, USN, recently explored the underlying assumptions concerning HSI statistical distributions in his thesis, "Evaluation of the Statistics of Target Spectral in HSI." LT Robertson discovered that conventional statistical models do not accurately represent target spectra, but that simple enhancements have the potential to

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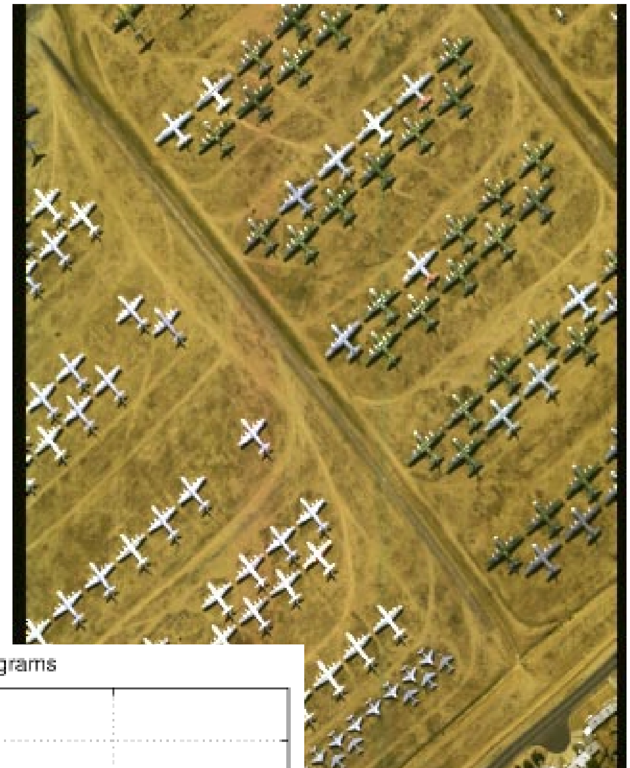
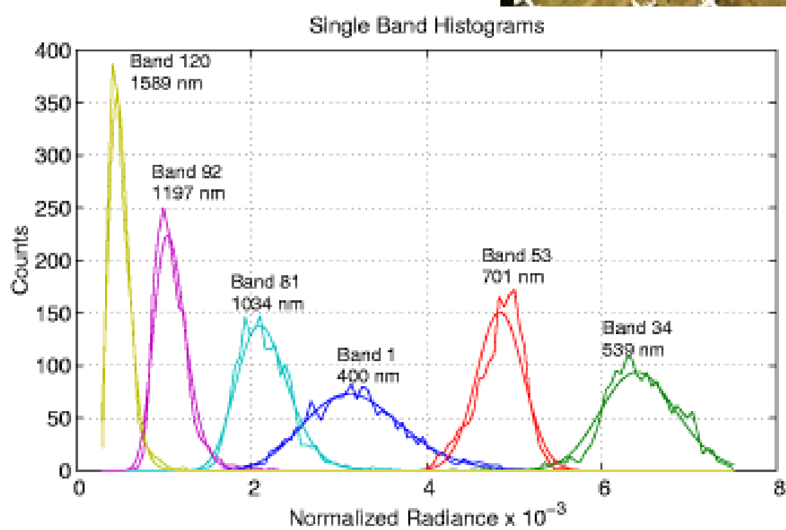
make a significant difference in the accuracy of statistical fits. Figure 2 presents an image of Davis-Monthan AFB along with actual and modeled statistical distributions. Current research is focusing on using the improved modeling to rapidly detect and classify targets in a spectral image.





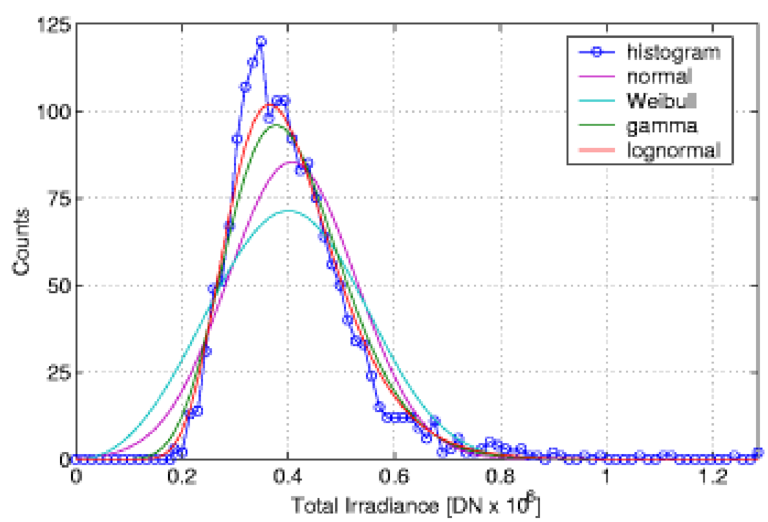


Figure 2. Image of Davis-Monthan Air Force Base along with actual and modeled statistical distributions.

The Fast Theater Model (FATHM)

FATHM is an aggregated joint theater combat model developed by **Professors Gerald Brown** and **Alan Washburn** of the Department of Operations Research. FATHM quickly answers "what if" questions about the numbers and effectiveness of resources committed to battle, particularly attack platforms and munitions. Battle is viewed as consisting of two parts conducted in parallel over a period of weeks or months: the Air-to-Ground part and the Ground-to-Ground part. Sea battle is not represented, nor is air-to-air battle except by assuming that Blue control of the air applies throughout. Ground-to-air battle is represented only in that air strikes in the Air-to-Ground battle do carry the implication of possible attrition. Battle occurs in phases, with phase transitions depending on battle results as well as minimum and maximum phase durations.

The Air-to-Ground part (hereafter simply the Air model) consists of a sequence of sorties by Blue platforms against Red targets. Most platforms are fixed-wing aircraft, but launchers of expensive munitions such as TLAM and ATACMS are also put in this category. This part of FATHM is optimized period-by-period using Linear Programming, very much in the spirit of models such as HEAVY ATTACK and CFAM. Platforms are attrited, but there is no explicit reference to the Red assets that cause the attrition. Attrition rates can therefore depend on time, but not on battle results. The sole influence of Red fixed-wing aircraft in FATHM is to cause diversion of Blue sorties against Red targets such as airfields, and possibly to influence the time-dependent

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TIME CRITICAL STRIKE, *continued from page 30*

attrition rates that are determined exogenously. Because Blue air superiority is assumed, only platforms involved in direct attack are modeled (SEAD, CAP, and ECM, in particular, are not modeled).

The Air model keeps track of munitions expenditure, and will respect any munitions constraints that are imposed. Indeed, one of the purposes of FATHM is to measure sensitivity to such constraints. The FATHM objective function flexibly acknowledges the importance of

- Ending the current phase quickly;
- Assuring an equitable distribution of effort over the services; and
- Avoiding attrition.

The Ground-to-Ground part of FATHM (hereafter simply the Ground model) is a Lanchester system incorporating both direct and indirect fire, with direct fire being reprogrammed to other targets in the event that some direct target is exhausted. The required attrition coefficients are obtained by pre-processing COSAGE killer-victim scoreboards that are appropriate to the phase. As in COSAGE, Red weapons are represented explicitly.

COSAGE runs typically include both Blue and Red fixed-wing aircraft, but FATHM ignores these. This is because Blue aircraft are represented instead in the Air model, and Red aircraft are assumed to cause no attrition on account of the underlying assumption of Blue air superiority. Red and Blue helicopters, however, are included in the ground model. The ground model does not keep track of munitions expenditure, and shares no munitions with the Air model.

The two models run in parallel, with each operating myopically and independently during each short time period. The period length has so far been taken to be three days, but a principle of FATHM is that all small lengths of time should produce essentially the same results. "Essentially the same" means that smaller lengths should be more accurate but more

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EXPLORING TIME CRITICAL STRIKE IN FLEET BATTLE EXPERIMENTS, *continued from page 4*

of the terrain and produce probabilities with respect to potential enemy weapons hide-sites, was necessary in order to produce quick decisions. Or the need for much better situational awareness by the watch officers making assessment of targets and decisions for strike was found to be of critical importance when coordinating efforts of different platforms.

While FBE Echo represented a C2 organization that was purposely centralized, the TCS experiment in FBE Foxtrot was quite different. FBE Foxtrot was conducted with Commander, Fifth Fleet, in Bahrain. The overriding concern in this area of the world is providing access to oil tankers transiting through the Straits of Hormuz. In this experiment the requirement of TCS had to be merged with the needs of mine warfare and ASW and surface warfare units engaged in opening and defending the straits. A Joint Fires Element (JFE) was the organization element built ashore in Bahrain, and was to provide the coordination of pre-planned missions in support of Navy access missions, with requirements to respond to TCS targets. A distributed C2 structure allowed a Joint Forces Maritime Component Commander embarked on a carrier to coordinate naval efforts, while also responding to TCS target requirements in accordance with guidance provided by the Commander Joint Task Force (CJTF) ashore, and overseen by the JFE. Again, technology was very important to the C2 and mission planning necessary to TCS. A much improved TCS targeting process was included, which reduced TCS planning time. Sensor products were delivered directly to decisionmakers and mensuration technology (this is the function that provides a global positioning system (GPS) quality position from a sensor image, which is necessary if a target is to be engaged with a precision targeting weapon) was used to define the target's position. This position was then paired with a weapon system through a Land Attack Warfare (LAWS) terminal. The "weapon-target-pairing" process provided by LAWS was critical to decreasing the time to engage TCS targets.

Decentralization of TCS efforts was partially explored in FBE Foxtrot, with some centralization still required in the Joint Fires Element. FBE Golf, on the other hand, explored the limits of Network Centric Warfare (NCW) applied to the TCS problem. In this experiment, conducted in conjunction with Commander, Sixth Fleet (having recently been involved in Kosovo operations, making this staff very aware of TCS problems), an attempt was made to make decisionmaking completely autonomous. That is, platforms with appropriate weapons could view sensor data and make decisions to engage TCS targets directly. This "command by negation" feature of TCS was envisioned to produce greatly reduced time requirements by limiting the decision layers necessary to process

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TIME CRITICAL STRIKE, *continued from page 31*

time consuming, as in solving ordinary differential equations. The two models influence each other through the effect on shared Red weapon systems.

New platforms, munitions, and targets can be scheduled to arrive in-theater by time period. In addition, a destroyed Red target may be repaired and regenerated. The likelihood that such a target can regenerate depends upon whether the kill was by an air attack or from ground fire.

FATHM has no "pistons" or any other kind of spatial representation other than a theater name. All combatants are regarded as being part of the same aggregate. However, the list of targets available to the Air model may include targets not represented in the ground model, and it is in principle possible for entities to change identity in a Markov fashion as time goes by. Thus the ground model might represent only tanks while the air model represents both tanks and deep tanks, with a certain fraction of deep tanks becoming tanks at the end of each period. In this limited sense movement between regions, or at least movement between populations that inhabit regions, is possible. The Markov method is also used to model dead targets that come back to life at the end of each period, a kind of repair process.

Real-Time Execution Decision Support (REDS)

Professor Kevin Wood of the Department of Operations Research has been awarded research funds by the Office of Naval Research to assist SPAWAR (Space and Naval Warfare Systems Center, San Diego) in developing REDS (Real-Time Execution Decision Support) for Time Critical Strike. REDS is essentially a competitor to the better-known Joint Mission Planning System.

REDS already has two modules that are close to deployment, the Element Level Planner (ELP) and the Mission Monitor (MM). ELP automates the administrative work involved in planning at the element level and MM will

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EXPLORING TIME CRITICAL STRIKE IN FLEET BATTLE EXPERIMENTS, *continued from page 31*

targeting data and decision to engage. The experimental information and C2 component, also the technology experiment, revolved around the production and use of Digital Target Folders (DTFs). Web-based folders were produced which all subscribers to the system and some autonomous systems could update. By employing this structure, weapons platforms could negotiate, or "bid" on the use of their weapon to engage a TCS target. The technology did indeed work well in this experiment, and when the system was used as proposed, timelines were indeed decreased. Authority issues surfaced, however, which necessitated that layers of authority be imposed on the TCS system, tending to negate timesavings. An important lesson learned in this experiment is that the TCS problem is a total *systems* problem, which includes the interactions and relationships of technology, procedures, doctrine, human factors and organization processes. Each of these must be properly integrated and responsive to produce a system result—a successful TCS engagement.

The latest FBE conducted, FBE Hotel, also explored the TCS problem, but from a considerably different perspective. The U.S. Air Force and Joint doctrine includes use of an Air Tasking Order as the principle process and document for conducting deliberately planned missions. A similar device for maritime use was proposed and experimented with in FBE Hotel. Here, a Maritime Tasking Order (MTO) was used as the instrument and process by which deliberate planning for maritime missions would be coordinated between the various maritime component commanders (ASW, MIW, Amphibious, Surface, Air and so forth) to support the CJTF's guidance in conduct of a campaign plan. An essential element to this planning is the *dynamic* relationship between deliberate strike planning and TCS targets. That is, as sensors are used for TCS missions, and weapons platforms respond, there are implications for deliberate planning, and these must be included in the MTO process in nearly real time. FBE Hotel provided an initial understanding of the technical and process requirements that must be met in order to properly *synchronize* these missions.

The essential elements shared in all FBEs, and what has been learned on a macro-level with respect to TCS, has to do with requirements for network centric information management, sensor management, technology for enhanced situational awareness (a common operational picture, or COP), synchronization of missions (deliberate and time-critical), damage assessment, and coordination of effects. Time-critical targeting and strike is exceptionally complex, and relevant for the Navy's future missions. Fleet Battle Experiments have helped to identify specifics with regard to these requirements, but much work is left to be done.

TIME CRITICAL STRIKE, *continued from page 32*

monitor all phases of an air-strike mission making a wealth of real-time data available for planning and execution, e.g., target information, aircraft load-outs and positions, etc.

The next stages (modules) of REDS will use the information coordinated by MM to partially automate the decision-making processes that comprise mission planning. For instance, REDS will:

- take available information on potential strike packages (groups of attack, jamming, and other aircraft that jointly execute a mission) and help the decisionmaker compose those packages and assign them to targets,
- identify routes to targets with low risk, acceptable fuel consumption, and high success probability, and
- provide probabilistic information on mobile-target locations. (Mobile targets include surface-to-air and theater ballistic-missile launchers, troops, etc.)

The proposed work at NPS will provide theoretical support for the next stages in the development of REDS. The initial focus will be on probabilistic information on mobile-target locations, predicting likely locations for mobile targets given reconnaissance information, terrain and road data, and

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OPTIMIZING TOMAHAWK STRIKES, *continued from page 5*

Predesignation considers more than just a particular salvo or mission at hand. We must keep track of where candidate platforms are, what they are doing, and when they are scheduled to leave the theater of operations. We want to preserve as much residual firepower—defined here as the remaining salvo size of each missile type—as possible on the combat platforms that will be remaining with the battle group in theater, avoid predesignations that interfere with other duties of the firing platforms, and expend TLAMs from platforms that will soon be departing the theater.

The TSC currently predesignates by hand. There are no Tactical Decision Aids, Naval Warfare Publications, or Tactical Memoranda to guide this complex decision.

Optimal decisionmaking is the central theme of operations research. And, the Department of Operations Research (OR) at the Naval Postgraduate School is always looking for important, fleet-relevant problems for which it can develop and apply appropriate solution technologies, and integrate these into officer-student education. OR has been supported by Naval Surface Warfare Center Dahlgren Division and the Office of Naval Research to develop an automated decision support tool to optimally predesignate TLAM strikes.

An automated tool must consider all the details governing the preparation and firing of every missile in every launcher on every platform. A significant part of the research effort has been devoted to capturing all the engineering details and merging these with Naval tactics.

Kuykendall [1998] breaks ground with the first comprehensive operations analysis of the TLAM predesignation problem.

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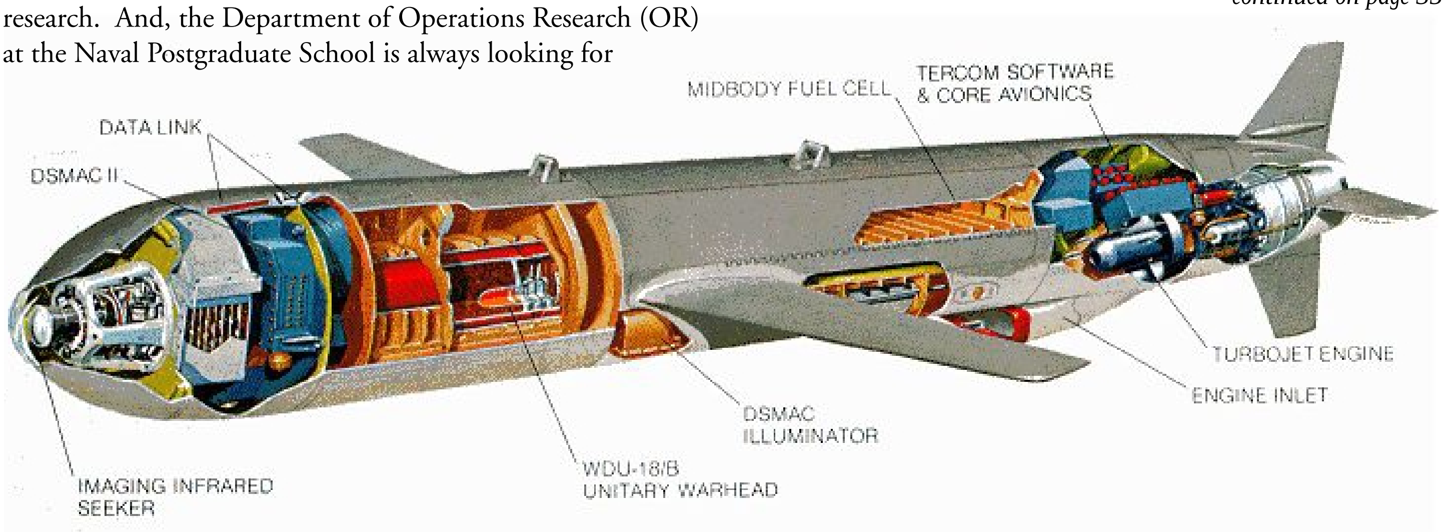

Tomahawk (BGM-109C) land attack cruise missile. Its turbojet propulsion can accurately deliver a 450 kg warhead more than 1,300 km. Guidance options include inertial, terrain contour match (TERCOM), digital scene matching area correlation (DSMAC), and global positioning satellite (GPS).

TIME CRITICAL STRIKE, *continued from page 33*

knowledge of the adversary's doctrine. Some of the relevant theory has been developed here at NPS in the context of anti-submarine warfare and tracking mobile, theater ballistic missiles.

Differential Global Positioning System (DGPS) Aids Precision Navigation

The Global Positioning System (GPS) provides a 3 to 6 m horizontal position anywhere at anytime. But what if that isn't good enough for your mission (minefield transit for example). Then you can improve the accuracy by using differential GPS (DGPS). In this case, a second GPS receiver at some known position provides corrections. At NPS, Research Professor James Clynch of the Department of Oceanography has been working on the techniques to use a ship for a DGPS reference station. Now there is no necessity to insert forces on some land to establish a differential station. Any large ship can serve as a reference station.

Tests on the *RV PT SUR* have demonstrated that it is possible to do this. The key is the use of large amounts of data, computer power and auxiliary data. Up to a day's data is used to initialize the system and at any one time up to hundreds of MBytes of data are being analyzed. The attitude of the ship is derived externally to the main GPS receiver and a precise geoid is used to establish the height of the ship in an earth-centered system.

With a system based on these principles deployed on aircraft or amphibious assault command ships, an operation can sail into an operational area and begin operations that require precision navigation without prepositioning personnel in the area, perhaps tipping off others to the intended place and time of an operation.

Issues and Applications when Using GPS-Guided Air-to-Ground Weapons Against Moving Targets

This research supports Time Critical Strike (TCS) initiatives being proposed by the Program Manager, Conventional Strike Weapons (PMA-201). The PMA-201 TCS concept seeks to enable the employment of existing low-cost precision weapon technology against mobile/moving point targets. The specific purpose of the thesis research being undertaken by CDR Randolph Mahr, USN, with advisors Associate Professor Russ Duren, Department of Aeronautics and Astronautics, and Professor Morris Driels, Department of Mechanical Engineering, is to examine and assess the error sources in the open loop sensor-to-weapon system.

The current intelligence gathering and decision infrastructure is optimized to handle fixed targets. Fixed targets generally allow cycle times in excess of 48 hours to complete the targeting cycle. However, there are a smaller number of exceptional targets that, because of their criticality to the overall objective of the campaign, require near immediate engagement. This class of target has been described as a Time Critical Target (TCT).

Most TCTs can be attacked using current weapons coupled with an accelerated decisionmaking process and rapid application of on-call strike forces. However, the strike warfare system cannot routinely deal with the special case of the moving target, particularly when the target is capable of self-defense, or when protected by overlapping air-defense systems. It is highly desirable to find an affordable means of employing currently fielded conventional standoff weapons against this class of target.

The current generation of low-cost standoff precision weapons (including JSOW, JDAM, and SLAM-ER) rely heavily on Global Positioning System (GPS) data to guide them to targets located at fixed geo-spatial coordinates loaded in the weapon prior to release from the launch platform. When attacking a fixed site, GPS guidance can provide sufficient accuracy to allow the elimination of costly seeker-based guidance systems. However, if the target is mobile (capable of relocating in less than the time required to execute the strike) or moving, GPS-only guidance is ineffective. Even with an onboard seeker, the weapon may still be limited by the field-of-regard of the seeker. Thus there is a lack of capability to attack time critical mobile targets with precision standoff weapons

PMA-201 has proposed addressing this deficiency by adding a data-link to the JSOW, and integrating this with the existing intelligence and decisionmaking infrastructure. The proposed concept is to use a constantly updated position (or velocity vector) from a tracking sensor (e.g. JSTARS, UAV, space-based) to supply constant coordinate update until impact. This is analogous to using 'command line-of-sight beam-rider' technology in surface-to-air missiles. The principal difference is the lack of any direct or indirect communication link between the sensors and the weapon. In addition, there are multiple nodes through which the information-beam must pass, each of which can introduce errors into the solution.

CDR Mahr's thesis will analyze the existing infrastructure

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TIME CRITICAL STRIKE, *continued from page 34*

which collects and produces target location information, and attempt to determine the errors associated with the data. Once the errors are bounded, an assessment will be made of the capability of the JSOW weapon to utilize this information effectively. The methods to be used include conducting an object-oriented analysis of the system including various sensors, the ground based coordinate generation system, transmission links, and the weapon kinematic and guidance capability. This analysis will provide a description of the system's context, a collection of data use-cases to define system behavior, a domain model to identify the roles and responsibilities of each object within the system, and a risk assessment centered on error tolerance and propagation.

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OPTIMIZING TOMAHAWK STRIKES, *continued from page 33*

He states the problem and how the Navy addresses it manually, assesses the capabilities of TLAM missile variants, illustrates the physical layout of TLAM launch cells, and expresses their engineering peculiarities. Kuykendall then proposes an optimization model to predesignate aim points to TLAMs to maximize residual firepower for either a battle group or a single platform.

In the best spirit of Operations Research, Kuykendall conjures examples to illustrate why this problem is non-trivial, and why using only common sense and thumb rules can lead to bad tactics.

Consider the following trivial attack plan requiring one missile of type "A" and one of type "B." The firing platform has its missiles stowed in rows. For engineering reasons, a missile salvo can include at most one missile from each row:

B A C B
C B A A

If we shoot "A" from the first row, and "B" from the second, the attack mission is satisfied.

However, we leave ourselves with insufficient residual firepower if the following mission calls for two "A's" or two "B's." On the other hand, had we chosen to shoot:

B A C B
C B A A

then we would have residual capability to fire any requested combination of two missiles in the next mission. You may have quickly seen the better salvo for this trivial example, but picture yourself having to solve the same problem with an attack plan calling for 100 predesignations to be chosen from 250 missiles on seven platforms, instead of these two predesignations from eight missiles on just one platform.

This trivial example is important for two reasons. First, Kuykendall shows the subtlety of the problem with elegant simplicity. Second, he points to what may have been a flaw in an early Navy attempt at automating missile predesignation. The first solution in the example typifies the inferiority of applying a simple rule of thumb, such as: Use the first "A" you find; then use the first "B."

Kirk [1999] isolates more of the nuances guiding

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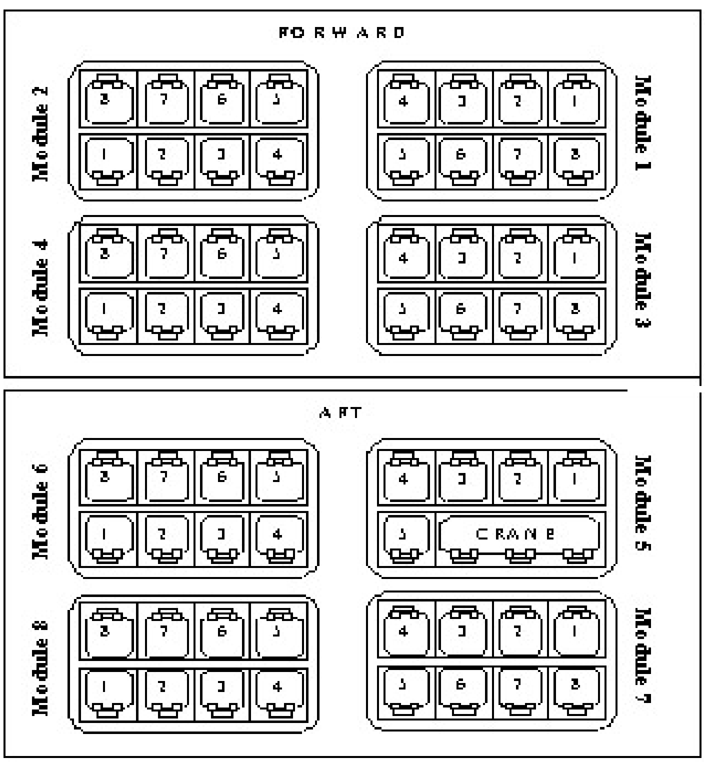

A Mark 41 Vertical Launching System. The 61 missiles are identified by module (F1,F2,…, F8) and cell number (1,2,….,8). Each row of four cells is called a half-module. Engineering restrictions prevent simultaneous usage of two missiles from the same half-module. A Ticonderoga Class cruiser has two full-size launchers, a Spruance Class destroyer has one, and an Arleigh Burke Class destroyer has a full-size launcher and a half-size launcher (modules 5-8 of this diagram).

TIME CRITICAL STRIKE, *continued from page 35*

The results of the effort will be provided to PMA-201 for use in preparing for prototype integration in Fleet Battle Exercises during 2001.

High Speed Propulsion System Reduces Time-to-Target After Launch

An important component of TCS technology is the propulsion unit of the tactical missile system being used or developed. Although the concept of TCS involves rapid targeting decisions, it also inherently requires a high speed propulsion system in order to reduce the time to target after launch. Additionally, it would be beneficial for such a system to possess the flexibility of variable thrust over a wide range of flight Mach numbers in order to allow for loitering and/or target reassignment post launch. The system may also require the capability to accelerate to very high Mach numbers for end-game situations. Although a combination of systems exist

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OPTIMIZING TOMAHAWK STRIKES, *continued from page 35*

predesignation. The most daunting challenge we face with automated decision support is inducing an objective assessment of the quality of a proposed decision. Kirk develops multiple, hierarchical objectives to assess effective TSC attack planning. While these objectives are not official doctrine, they have been reviewed by knowledgeable authorities and "found acceptable." In descending priority, the TSC should:

- maximize the number of targets designated to missiles, then
- minimize the use of firing platforms performing other duties in other areas, then
- maximize the use of missiles from firing platforms that will soon leave a theater of operations, then
- minimize the deviation from the mean on each firing platform of the residual missile inventories among firing platforms that remain in a theater of operations, then
- if desired, maximize the number of firing platforms with predesignations, then
- minimize the use of "over-qualified" missiles for a predesignation, and finally
- maximize residual firing capability.

Kirk develops a number of ambitious, extremely detailed mathematical optimization models. He tests them with scenarios provided by the research sponsor. Kirk's solutions and analysis establish that the essence of Tomahawk strike planning has been captured, and that the strike plans can be optimized. Kirk's objectives can be reordered, redefined, prioritized, or softened with the use of aspiration levels that seek most of the optimal value of each function, but not all of it, thus providing more flexibility for lower-level considerations.

Hodge [1999] develops a prioritized target list that he uses to mimic the optimal decisions of Kirk's most comprehensive model with a fast heuristic algorithm that selects firing platforms, and then predesignated targets from the list in a single pass. When the target ordering priorities are well stated for the scenario at hand, this one-pass heuristic suggests good strike plans very quickly. To prove this, Hodge uses Kirk's much slower, but optimal, results for qualitative assessment. Hodge's heuristic takes less than a minute to deliver strike plans good enough for operational use.

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Flying her battle flag, *USS Shiloh* (CG-67) fires a Tomahawk land attack missile in Operation Desert Strike, 3 September 1996. (U.S. Navy photo)

TIME CRITICAL STRIKE,

continued from page 36

today which can provide this capability, a single propulsion unit which could deliver such flexible performance at a reasonable cost is desired.

Research efforts by **Research Assistant Professor Christoper Brophy**, Department of Aeronautics and Astronautics, **Maj Paul Damphousse, USAF** (December 2001), **LT Neil Sexton, USN** (June 2001), and **Office of Naval Research/American Society for Engineering Education Post-Doctoral Associate Jose Sinibaldi** at the Rocket Propulsion and Combustion Lab (RPCL) include the investigation of the performance and design issues related to a new type of propulsion system known as Pulse Detonation Engines (PDE). These systems are relatively simple and may be operated from subsonic to supersonic flight Mach numbers. The increased thermodynamic efficiencies of these systems should result in increased range while providing the ability to vary thrust levels and therefore flight Mach numbers. Since these systems will generally not require turbomachinery or high pressure feed systems, the structural weight may be significantly reduced when compared to current tactical cruise missile systems therefore resulting in high thrust-to-weight values and an increased capacity for fuel, avionics, and/or warhead size.

The PDE research is sponsored by the Office of Naval Research and is structured to feed directly to industry and system development teams. This provides the opportunity to interact with propulsion engineers and system designers, which aid in directing the ongoing research into specific problem areas. The NPS effort is currently focused on the use of liquid missile fuels such a JP10 and the problems associated with their use in a PDE system. Preliminary performance results appear promising and the knowledge gained will eventually contribute to the design of a full-scale demonstrator. Hopefully, this technology may be utilized in TCS system-level decisions and platform designs to reduce mission execution times and costs.

OPTIMIZING TOMAHAWK STRIKES, *continued from page 36*

Arnold [2000] improves Hodge's strike plans, and adds assurance that a recommended strike plan cannot be improved by any simple adjustment. This is key to retaining the hard-earned confidence of planners who might otherwise lose faith if some minor blemish were to be discovered in a near-optimal heuristic solution. Arnold also accommodates:

- submarine launch platforms with their unique capabilities,
- the restriction of individual aim point assignments to a single firing platform to minimize collateral damage,
- the assignment of special types of redundant predesignations, and
- manual prioritization of the targets.

For a scenario with 104 targets and seven firing platforms, the Arnold heuristic delivers a complete strike plan in less than ten seconds. Equally important, we can forecast the necessary computation time for Arnold's heuristic. This is key for real-time decision support.

Kubu [2001] suggests modifications (e.g., shifting the launch time of a missile) in the event that a predesignation cannot be made. These modifications can help the TSC arrive at a list of targets and their associated attributes such that under heavy strikes, most of the intended targets can be struck with minimal alterations to the original plan. The modifications would be proposed if and when an initial application of the heuristic deems certain missile-to-target predesignations infeasible based on missile inventories, the number and type of missiles required for the strike, and target attributes (e.g., the launch time for a missile to ensure on-time arrival at the target).

Wingeart [2001] is comparing our automated strike planner with actual Fleet exercise decisions. The idea is to reconcile our results with those of experienced decisionmakers to make sure that the automated tool captures subtle human reasoning that may have been overlooked. He is also developing an interactive mode by which the TSC can manually control all or part of the heuristic, while continually receiving guidance from the heuristic on the influence his changes have on overall strike efficiency. This enhances the credibility of an automatic tool that, by its nature, should be received skeptically: There will be extenuating circumstances that cannot be anticipated and incorporated in advance.

We have developed a graphical user interface to maintain and display the state of every combatant, every launcher, and every missile. The interface has drill-down and fly-over features to permit arbitrary navigation among all the data elements and displays: This is important, because the TSC needs a global view of his battle group. It is vital to try to display not only which TLAM to fire from which platform and position, but visible reckoning of why. We also display aggregate statistics that measure the state of battle group firepower as a consequence of any action taken. This graphical user interface is the vehicle

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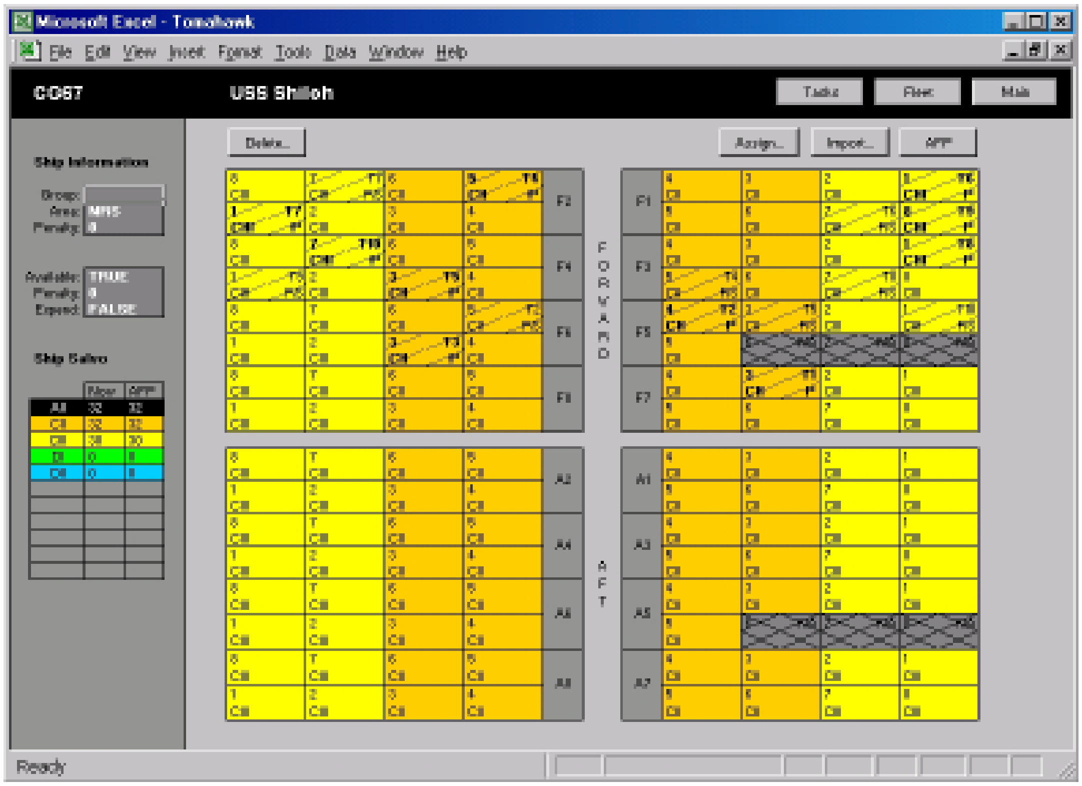
OPTIMIZING TOMAHAWK STRIKES, *continued from page 37*

Wingeart's manual method will use to directly accept guidance from the TSC.

Research on optimization of TLAM strikes continues with collaboration among our faculty, a succession of surface naval officer graduate students, and fleet experts at Dahlgren. The faculty provide guidance and continuity, the students are highly motivated by their anticipation of actually using their tools when they get back to sea, and Dahlgren will ultimately test, approve, document, and issue a product to our fleet.

Acknowledgements

We are grateful for the continued ideas, input, interest, and support from Dr. Charles Fennemore and Mr. Robert Taft of the Naval Surface Warfare Center, Dahlgren Division, who first brought this research topic to the Naval Postgraduate School.



User Interface View of *USS Shilo* (CG-67) Tomahawk Status. This screen highlights with cross hatching the predesignation of a salvo of Tomahawk missiles. Primary assignments are displayed in bold. Redundant designations—used in case a primary fails—are shown in standard font. Codes shown in each cell indicate the assigned task number (T1,T2,…), primary or redundant (P, RS) and type of tomahawk missile (CII, CIII). The type of missile is also discernable by the color of the cell. The left-hand side of the screen shows summary information about the battle group and the *Shilo's* missile load before and after the designated missiles are fired. Each ship has such a display, and companion displays (not shown) detail tasking and other details. One button on this dashboard optimizes an entire fleet-wide Tomahawk strike.

References

- Arnold, Andrew. 2000, *A Fast Heuristic For Land Attack Predesignation*, M.S. Thesis in Operations Research, Naval Postgraduate School, Monterey, CA, June (Advisors: Newman/Brown).
- Hodge, Bertram C. 1999, *A Heuristic For Land Attack Predesignation*, M.S. Thesis in Operations Research, Naval Postgraduate School, Monterey, CA, December (Advisors: Newman/Brown).
- Kirk, Brian D. 1999, *Tomahawk Strike Coordinator Predesignation: Optimizing Firing Platform and Weapon Allocation*, M.S. Thesis in Operations Research, Naval Postgraduate School, Monterey, CA, September (Advisors: Newman/Brown).
- Kubu, Justin. 2001, forthcoming M.S. thesis in Operations Research, Naval Postgraduate School, Monterey, CA, December (Advisors: Newman/Brown).
- Kuykendall, Scott D. 1998, *Optimizing Selection of Tomahawk Cruise Missiles*, M.S. Thesis in Operations Research, Naval Postgraduate School, Monterey, CA, March. (Advisors: Rosenthal/Brown)
- Wingeart, Paul. 2001, forthcoming M.S. thesis in Operations Research, Naval Postgraduate School, Monterey, CA, December (Advisors: Newman/Brown).

PROPOSED SHIPBOARD NAVIGATION DISPLAY, *continued from page 7*

then the TVE display would illuminate one white and five red lights to indicate the approximate number of degrees off station (Figure 2) – the desired station is 175°. Subjects viewed the virtual environment through a head-mounted display with a field-of-view of approximately 60 degrees. The subject's task was to maintain station 175° relative at 300 yards astern of the aircraft carrier for each of the five course track changes. Results showed that the TVE display had significantly fewer range and bearing errors than the non-navigation display condition did (Figure 3). The navigation display provided immediate feedback as to whether the aircraft carrier had changed bearing or speed, thus enabling the operator to initiate the appropriate input to maintain station astern of the carrier. Furthermore, Evanoff and Krebs (in review) had SWOs maintain station astern of the aircraft carrier while simultaneously performing an auditory mental arithmetic secondary task. Evanoff and Krebs (in review) found the TVE display had a smaller position error than the normal lighting display had.

This past summer, VADM Giffin (COMNAV-SURFLANT) who is now retired, RADM Gimmell (CNO-N885), and VADM Mullen (CNO-N86) who is now Second Fleet were briefed on the project and were enthusiastic about the potential of this system for Naval shipboard operations. They recommended that we test and evaluate the shipboard display on an aircraft carrier immediately. We were funded by the Office of Naval Research to develop, test, and evaluate an operational TVE display for aircraft carrier operations. After several

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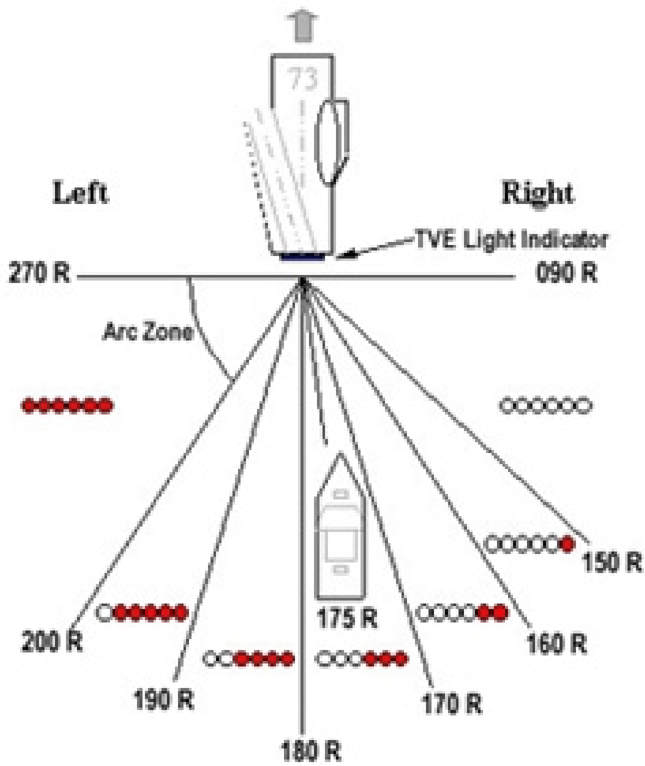

Figure 2. The red and white color system indicates the escort ship's relative position astern of the carrier. The desired station is 175° relative. As the ship's position changes relative to the carrier's stern, the light display changes color indicating approximate degrees off station. The conning officer can also interpret the aircraft carrier's range by the size and spacing of the lights from the combatant vessel.

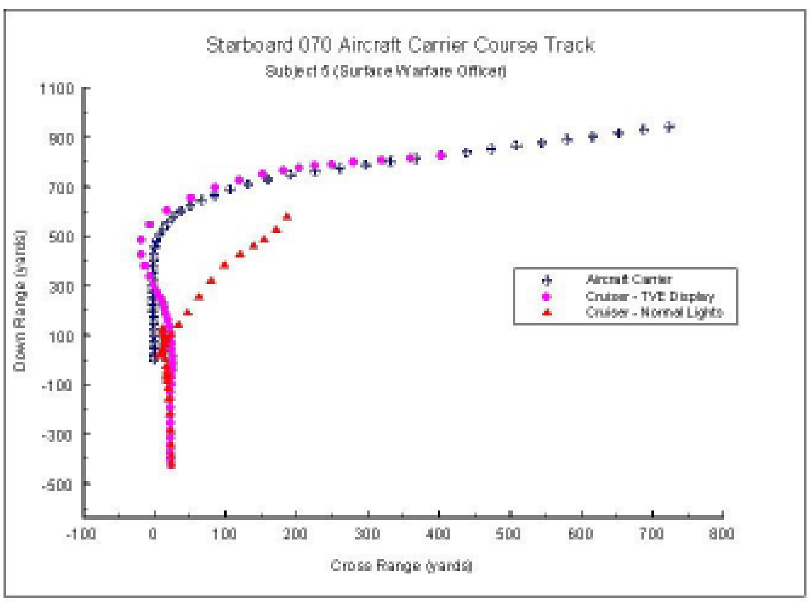

Figure 3. Illustrates a dynamic trial of the carrier turning 070° starboard (✣). The SWO initially tracked the carrier (Δ), but became disoriented after the carrier started its turn. The subject, unsure of the carrier's movement, reversed direction to avoid a collision then initiated full forward momentum to catch the carrier. The SWO using the TVE (●) immediately detected the carrier's starboard turn. The subject crossed the carrier's wake; stayed outside the wake until the carrier steadied on the 070° course heading; then proceeded back across the wake to regain plane-guard station. This was a textbook example of a proper ship maneuver when following a carrier.

PROPOSED SHIPBOARD NAVIGATION DISPLAY, *continued from page 39*

attempts, we developed the TVE unit which consists of six individual light units manufactured from a combination of a non-corrosive plastic and aluminum (Figure 4). Our laboratory tests showed that a red and green combination of lights was the best combination of hues for color discrimination.

Figure 4. One of six light units from the TVE display. The single unit size is 18" (length) by 8" (height) by 10" (width). The unit was manufactured from non corrosive plastic and aluminum with a 105 watt halogen bulb.

As part of the Office of Naval Research FY00 project (funded by Dr. Joel Davis, Code 34, and Mr. George Stimak, Naval Fleet/Force Technology Innovation Program), we conducted a flight test to determine whether the TVE display would be clearly visible to an escort ship conning officer, but invisible to a carrier pilot attempting a night landing. Aviators voiced concern that the TVE would obstruct or confuse pilots while approaching the carrier at night. We designed the TVE display's angle of visibility to be one degree from the TVE lights mounted on the stern of the aircraft carrier to the horizon, well outside the pilots' visibility while approaching the carrier - typically the pilot's glide path angle ranges between 3 to 4 degrees (Figure 5). On October 12, 2000 at McMillan Airfield, Camp Roberts, CA we conducted a day and night flight test. A California Army National Guard UH-1H helicopter approached the TVE display positioned at the end of the runway at different ranges at various altitudes ranging from 50' to 1000' above ground level (Figure 6). If the TVE display was directed one degree of visual angle or lower relative to the ground, pilots were unable to detect the TVE lights. However, if the TVE lights were directed upward to the sky, pilots were able to navigate to the runway using the TVE display (Figure 7). Although the TVE was not designed to aid aviator navigation, the effect would be similar to a combatant's conning officer navigating

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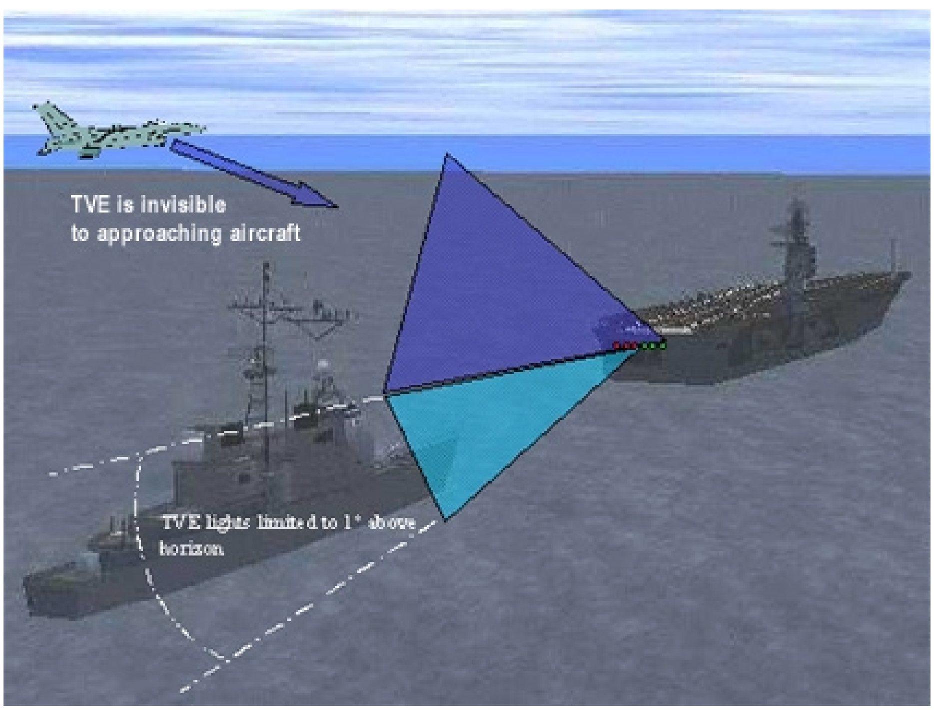

Figure 5. Illustration of the TVE mounted on the stern of an aircraft carrier. The TVE lights will be mounted underneath the aircraft carrier's stern overhang structure to occlude stray light as well as the light units will be directed downwards with a maximum one degree of visual angle above the horizon. Aviators landing on the aircraft carrier maintain a safe glide slope of approximately 3 degrees of visual angle, 2 degree glide slope the landing signal officer issues a wave-off warning, and a one degree glide slope the aviator will hit the bridge of the combatant.

PROPOSED SHIPBOARD NAVIGATION DISPLAY, *continued from page 40*

astern of an aircraft carrier. The success of the Camp Roberts flight test led the Office of Naval Research to fund a FY01 aircraft carrier demonstration this winter.

In January 2001, LCDR Evanoff presented our results to AIRLANT. So far, AIRLANT representatives are enthusiastic about the TVE project and would like to assist with an east coast aircraft carrier demonstration in the next couple of months. In addition, the Office of Naval Research requested that we form an Integrated Product Team (IPT) to ensure that the TVE can be transitioned to the fleet. The IPT includes representatives from OPTEVFOR, AIRLANT, ONR, and NAVSEA. The OPTEVFOR representatives will assist with the transition as well as participate in the aircraft demonstration test and evaluation.

Figure 6. Dr. William Krebs and Tom McCord position the TVE display on McMillan Airfield, Camp Roberts, CA, for a day and night flight test.

References

Evanoff, T.V. and Krebs, W.K. (in review). Conning Officers' Situational Awareness Increased by Using a Tactical Vectoring Equipment Display.

Evanoff, T.V. (1999). Design and Analysis of a Shipboard Visual Navigation Aid for Vessels in Formation. Master of Science in Operations Research, Naval Postgraduate School, Monterey, CA.

Krebs, W.K., Evanoff, T.V., and Sinai, M.J. (2000). An Evaluation of a Shipboard Collision Avoidance Display. *Proceedings of the International Ergonomics Association and the 44th Annual Meeting Human Factors and Ergonomics Society, 44(3)*, 431-434.

Martenak, J. (1999, July). Long range lineup system. Paper presented to the Chief of Naval Operations Aviation Warfare Division Codes N88 and N885, Washington D.C.

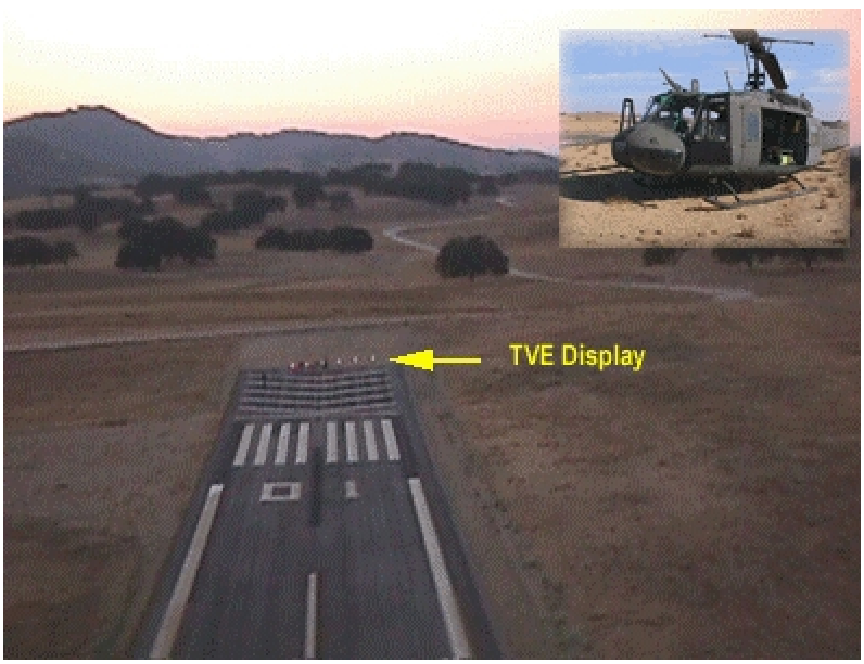

Figure 7. On October 12th, 2000 pilots CW3 Clark Barton and CW3 Kathy Lindberg and crew personnel CW4 William Richardson and SSG Irene Holland from the California Army National Guard flew their Bell UH-1H helicopter over McMillan Airfield simulating fighter aircraft landing on a carrier at night. This helped researchers conduct a controlled shore-based evaluation of the navigation system in preparation for an at-sea test scheduled early this year.

Additional information is available from Dr. Krebs. He may be reached by e-mail, william.krebs@faa.gov or his mailing address is Federal Aviation Administration, 800 Independence Avenue, S.W., AAR-100 (Room 907), Washington D.C. 20591.

TOWARD UNDERSTANDING NAVY KNOWLEDGE FLOW, *continued from page 9*

inherently supportive in nature; that is, this class of implementations and techniques to organize, formalize and distribute knowledge in the enterprise *supports* people in the organization, whom in turn apply, evolve and create knowledge in the organization. Alternatively, the latter three, non-sharing activities are adjacent on the left-hand side of the cycle. But these activities do not correspond well with support from extant information technologies or management practices, so they are grouped under the "Class II" heading in the figure. Such systems are inherently performative in nature; that is, this class of implementations to apply, evolve and create knowledge in the enterprise *performs* knowledge-management activities, either in conjunction with or in lieu of people in the organization.

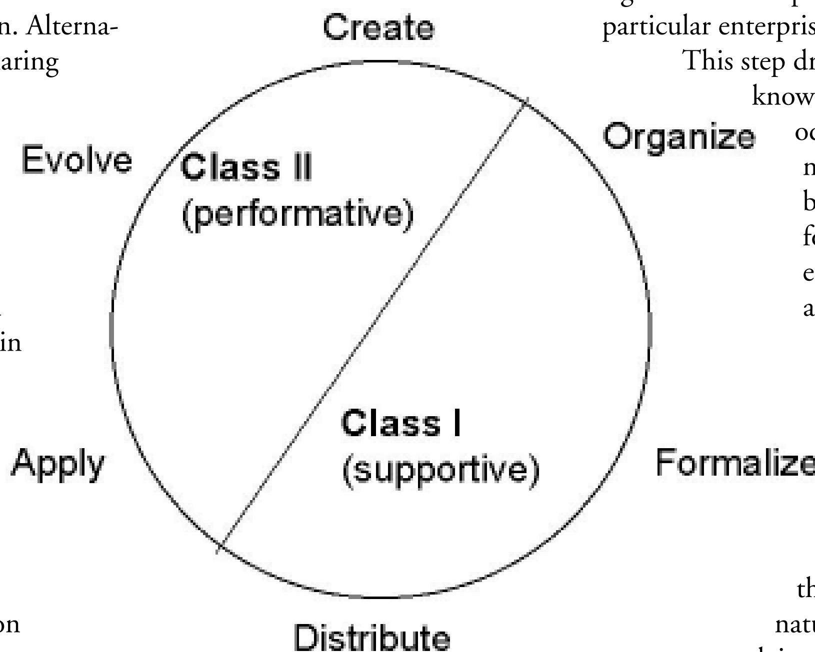

Figure 2. Knowledge Management Life Cycle.

Third, collaborative research by several NPS faculty members resulted in development of an effective method to address how information system design can be integrated with knowledge process design. This four-step method is summarized in terms of an integrative framework through Table 1. In short, one first analyzes the processes associated with knowledge work performed in the enterprise. This step draws from common business process re-engineering methods; that is, each process of interest must be understood and analyzed—and perhaps redesigned—to interpret the knowledge required for its effective performance. The next step is to identify and analyze the underlying knowledge itself. Central to the technique is the identification and analysis of critical success factors (i.e., the activities that must be performed effectively in order for the enterprise mission to be successful), which is useful to identify what knowledge is critical to process performance in a particular enterprise setting and context. This step draws from textbook knowledge engineering methods employed for development of expert systems, because such methods focus directly on knowledge—as opposed to data and information.

In the third stage of analysis, one assesses the contextual factors associated with each process of interest. Critical in this assessment is understanding the organization and the nature of knowledge underlying the task. Specifically, the role of organizational memory, organizational structure, incentives used to stimulate workers to contribute knowledge to systems and the distribution of canonical and non-canonical knowledge and practices through the enterprise exert strong constraints over the types of systems that can be employed for knowledge management. Finally, armed with results from these three levels of analysis (i.e., process, knowledge and context), one can then effectively analyze and design the information systems (IS) required to automate and support knowledge work in the process. Traditional IS methods (e.g., use of data flow diagrams, entity-relationship diagrams, object models, use cases) are employed to accomplish this, final stage of analysis.

Step	Activity
Step 1	Process analysis & (re)design
Step 2	Knowledge analysis & representation
Step 3	Contextual analysis
Step 4	IS analysis & design

Table 1. Steps of Integrative Framework.

Current Work

The integrated framework from above has been used to guide several research projects focused explicitly on naval and maritime processes. We briefly summarize early results from two such projects here: 1) carrier battlegroup theater transition process, and 2) maritime interdiction process. A number of other projects also address naval and maritime processes—

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TOWARD UNDERSTANDING NAVY KNOWLEDGE FLOW, *continued from page 42*

such as the special warfare mission planning process, sailor/job-assignment process, library-research process, and information systems operations curriculum access—but space prohibits covering them here. Details are available through the selected references included below.

The first project seeks to decrease the time required for a carrier battlegroup to familiarize itself when arriving to a new theater of operations. It focuses in particular on the quarterly battlegroup rotation that occurs in the Persian Gulf and identifies the intelligence process as one of the most critical in terms of knowledge flow. Specifically, intelligence personnel on board carriers and other battlegroup vessels require considerable time to develop an understanding of various actions and events in a new operational theater. Such an understanding pertains in particular to establishing and recognizing patterns and trends (e.g., flight paths of allied, neutral and enemy planes in the region), which directly impacts the battlegroup's ability to anticipate and respond quickly to a diversity of threats, indications and warnings that may occur in theater.

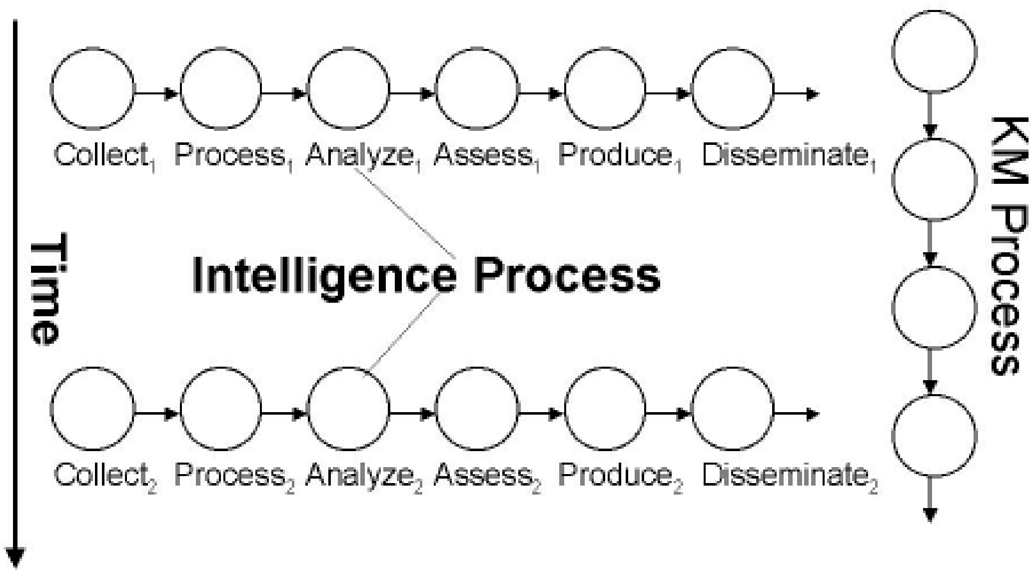

Figure 3. Battlegroup Intelligence Process Instances.

The key idea is to decrease the time required to develop such an understanding, and the project emphasizes knowledge flow between the departing battlegroup (i.e., the one that has been on station for three months) and its arriving counterpart. This knowledge flow is roughly operationalized in terms of action; that is, we measure the degree of knowledge flow in terms of how many days after arrival in theater are required before the performance and actions of the arriving battlegroup match the efficacy and appropriateness of those corresponding to the departing group. This is notionally depicted in Figure 3. Two instances of standard activities associated with the intelligence cycle are depicted as part of the battlegroup intelligence process as separate horizontal directed graphs. Subscripts associated with each activity indicate which instance of the process is being performed. An arrow of time is shown between the first and second instances to indicate they do not take place concurrently. The other directed graph, depicted vertically in the figure, suggests *a key aspect of knowledge management pertains to processes that run across various instantiations of the intelligence cycle* (e.g., as performed by different battlegroups, at different times).

The second project involves maritime interdiction. The maritime interdiction process is associated with locating, stopping, boarding and inspecting suspicious vessels at sea. Such actions are targeted for ships suspected of violating laws (e.g., against trafficking drugs, smuggling illegal aliens) and policy restrictions (e.g., enforcing embargoes, blockades), and the project emphasizes knowledge flow between personnel that are experienced with specific interdiction situations (e.g., drug seizures in the Caribbean Sea, Iraqi oil smuggled through the Persian Gulf) and their counterparts that are not. With certain duties that require considerable time and on-the-job experience to develop expertise, personnel are frequently transferred just as they achieve proficiency, and teams with personnel transferring in and out require time and practice to develop group-level coordination, trust and competence.

An important contribution from this project is the verification of and elaboration on the distinction, alluded to above, between *horizontal processes* and *vertical processes*. Briefly, horizontal processes describe the key flow of activities required to perform organizational work and accomplish goals. Enforcing the No-Fly Zone, collecting battlegroup intelli-

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gence, interdicting Iraqi oil shipments, tracking Iranian aircraft activities, and navigating through littoral waters each represents an instance of a horizontal process. This term gets its name from the manner in which most process diagrams depict enterprise processes in terms of horizontal workflows.

In contrast, vertical processes pertain to performance *between instances* of horizontal processes; that is, vertical processes enable, support and facilitate the level and consistency of performance across horizontal processes performed at different points in time and/or by different organizational units. Examples of such vertical processes include personnel selection and classification, distribution and assignment, after-action review, qualification, pre-deployment brief, education and training, post-deployment debrief, and IT support. Each of these vertical processes is useful to support diverse instances of the horizontal process. Unlike the horizontal, work-process flows, which pertain to the performance of work in the enterprise, the vertical, cross-process flows pertain to the process of knowledge management itself. Results from this study suggest *the key to knowledge flow lies in performance of such vertical processes.*

Agenda for Continued Research

Clearly, research to understand Navy knowledge flow remains in its infancy. To become broadly impactful, additional research along these lines is required, and the researcher needs to work closely with the Fleet to ensure valid conceptualization and useful implementation of the ensuing ideas and technologies. An abbreviated research agenda toward this end is outlined here, intended more to provoke new thinking than to attempt to be comprehensive or even suggest specific projects and research approaches. This agenda is characterized through three, open research questions that can be used for guidance.

- *What theoretical models can describe, explain and predict knowledge flow?* The primary objective of this proposed research stream is to develop scientific knowledge and understanding (i.e., theory) pertaining to the phenomenon of knowledge flow. In the context of knowledge-centric warfare, good theory—that can *describe* a variety of knowledge systems and processes, *explain* why certain practices and systems are successful while others are not, and *predict* which organizational and technological interventions offer the greatest likelihood of performance improvement—should be very useful to the Navy leadership and help advance science and understanding pertaining to knowledge and its flow through the very-large enterprise.
- *How can knowledge-flow theory be applied to inform the design of systems and processes in very-large enterprises?* Building upon great progress and success in the physical sciences, engineers in many disciplines (e.g., aerospace, civil, electrical engineering) are able to apply underlying theory and knowledge to design and build useful devices (e.g., airplanes, bridges, computers). As knowledge-flow theory is developed, it is similarly important to apply it to design and build effective systems and processes for automation and support of knowledge work.
- *What impact on enterprise performance can knowledge-flow systems and processes effect?* It does little good to develop knowledge-flow theory and its associated devices unless they can be implemented and demonstrated to have a positive impact on enterprise performance. As with other engineering disciplines, modeling and simulation can play a major part in the evaluation of alternative knowledge-flow designs, and one would expect to pursue advanced technology concept demonstrations and pilot projects before implementing new processes, organizations and technologies Fleet wide. But concurrent with the kinds of exploratory, theoretical and developmental work called for in this proposed research stream, we must, from the beginning, target Fleet implementation and impact as our principal objective.

Selected References

- Davenport, T.H. and Prusak, L. *Working Knowledge: How Organizations Manage What They Know*. Harvard Business School Press: Boston, MA (1998).
- DoN CKO. "Department of the Navy Knowledge-Centric Organization Toolkit," CD-ROM distributed by the Navy Chief Information Officer (2000).
- Espino, J.P. *Innovating the United States Coast Guard Law Enforcement Detachment (LEDET) Deployment Process Through Knowledge Management.* Masters Thesis, Naval Postgraduate School (September 2000).
- Gates, W.R. and Nissen, M.E., "Designing Agent-based Electronic Employment Markets," *Electronic Commerce Research Journal*, Special Issue on Theory and Application of Electronic Market Design (forthcoming 2001).
- Mayer, K.A. and Schroeder, J.A. *Innovation of the Naval Postgraduate School's Student Thesis Research Process through Knowledge Management*. Masters Thesis, Naval Postgraduate

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SOFTWARE ENGINEERING PROGRAM,

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exhibits the desired behavior. In contrast to many prototype engineering systems, CAPS allows the prototype to be used in the construction of the actual system.

CAPS has also been used to prototype the interface for a wireless acoustic cardiac and respiratory monitor called the "SIDS Wireless Acoustic Monitor (SWAM)"[5]. SIDS stands for the Sudden Infant Death Syndrome. It is the leading cause of death among infants. A vital aspect of treating infants at risk for SIDS is the monitoring of their respiration and pulse while they are asleep. Current monitoring methods utilize wires and traditional trans-thoracic impedance monitors, which are placed on the patient using adhesive. SWAM uses a fluid filled pad as the primary sensor to "listen to" the heart and lung sounds of an infant. Some of the fundamental principals are similar to current technology used in undersea acoustics to listen for and distinguish between different types of ships, submarines, etc. The use of the acoustic pad enables the patient to be monitored in a wireless fashion, without the attachment of electrodes to the torso (Figure 2). SWAM eliminates adhesive, electrodes and wires, so that patients can be monitored via their cardiac and respiratory sounds. SWAM was created using an iterative requirements development process involving users and implementing changes to the requirements as development progressed. The iterative design approach and the use of CAPS facilitated the development of the SWAM prototype in less than eight months.

Prototyping can contribute substantially to the process of re-engineering legacy systems[6]. Most legacy systems are too complicated for individuals to understand. We found that constructing even a very thin skeletal instance of a proposed new software architecture using CAPS raised many issues and enabled us to correct, complete, and optimize the architecture for both simplicity and performance. This was done before the architecture had grown into a maze of dependent design and implementation details. Consequently, the changes could be realized without incurring the large cost and time delays typically encountered later in the development.

Students were intimately involved in all of these efforts gaining valuable skills and experiences that they can apply to

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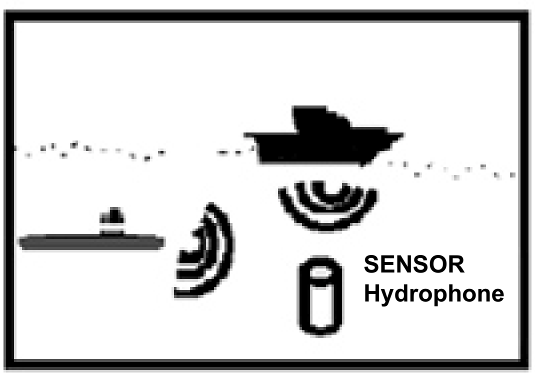
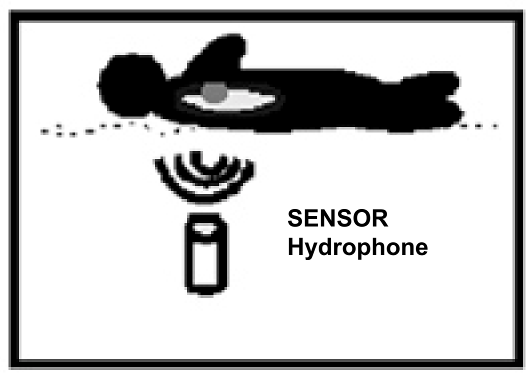


Current acoustic monitoring and noise filtering can monitor and differentiate between various sources.



The SWAM is an extension of current technology, separating respiratory and cardiac sounds, potentially replacing the traditional impedence monitoring approach.

Figure 2. Illustration of the Overall Acoustic Pad Concept.

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School (September 2000).
- Nissen, M.E., Kamel, M.N. and Sengupta, K.C. "Integrated Analysis and Design of Knowledge Systems and Processes," *Information Resources Management Journal* 13:1 (January-March 2000).
- Nonaka, I. "A Dynamic Theory of Organizational Knowledge Creation," *Organization Science* 5:1 (1994).
- Oxendine, E. *Knowledge Management Support to Network-Centric Warfare (NCW)*. Masters Thesis, Naval Postgraduate School (September 2000).
- Spence, W.W. *Knowledge Management for the Special Warfare Automated Mission Planning System (SWAMPS): How to Provide Timely, Relevant and Accurate Knowledge to the Operator During the Mission Planning Process*. Masters Thesis, Naval Postgraduate School (September 2000).
- Walker. A.M. *Knowledge Portal Support to the Naval Postgraduate School's Network-Based Learning Program for the Information Systems and Operations Curriculum*. Masters Thesis, Naval Postgraduate School (December 2000).

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their future DoD responsibilities.

Software Engineering Contributions to DoD
Our expertise in real-time embedded system design, stemming from the fundamental research supported by the National Science Foundation's Presidential Young Investigator Award and the U.S. Army Research Office, helped the Naval Surface Warfare Center (NSWC) to define the field of Systems Engineering required to tackle systems development that includes hardware, software and human resources during the early nineties. NPS software engineering faculty also assisted the Naval Research Laboratory (NRL) in developing resources (human and technology) for real-time system development.

Professor Luqi worked with Dr. Winston Royce, a pioneer in software process research, in redefining the life cycle model for software development. Dr. Royce's Waterfall Software Life Cycle Model was used by DoD during the late 1980s to manage some of the most significant software procurements. However, DoD software practitioners discovered that the model failed to accurately represent the iterative nature of embedded software development within complex systems because it was not possible to properly define the system requirements at the beginning of the Waterfall life cycle. Our iterative prototyping process was endorsed for adoption by Dr. Royce, at that time still a DoD technology advisor, and the IEEE Software Industrial Advisory Board as an effective alternative approach to assess and evaluate complex software[7] . It directly assisted in changing the way DoD designed and built embedded software.

Assistance was also provided to DoD in the conduct of feasibility studies to assess new approaches to the development of weapons-related software. In 1990, Luqi was tasked by the Office of the Chief of Naval Operations (CNO) to conduct a conceptual study of the feasibility of integrating Command, Control, Communications and Intelligence (C^3I) systems using software. These C^3I applications have proven difficult to develop due to: 1) Their use in strategic defense applications which is influenced by many stakeholders (people, organizations, policies), making their system requirements very complex and difficult to define; 2) Their stringent requirements regarding correctness and reliability; and 3) Their heterogeneous nature requires complex and dynamic user and system interfaces. While initially difficult to develop, changes to these systems have proven to be almost impossible to deal with over time.

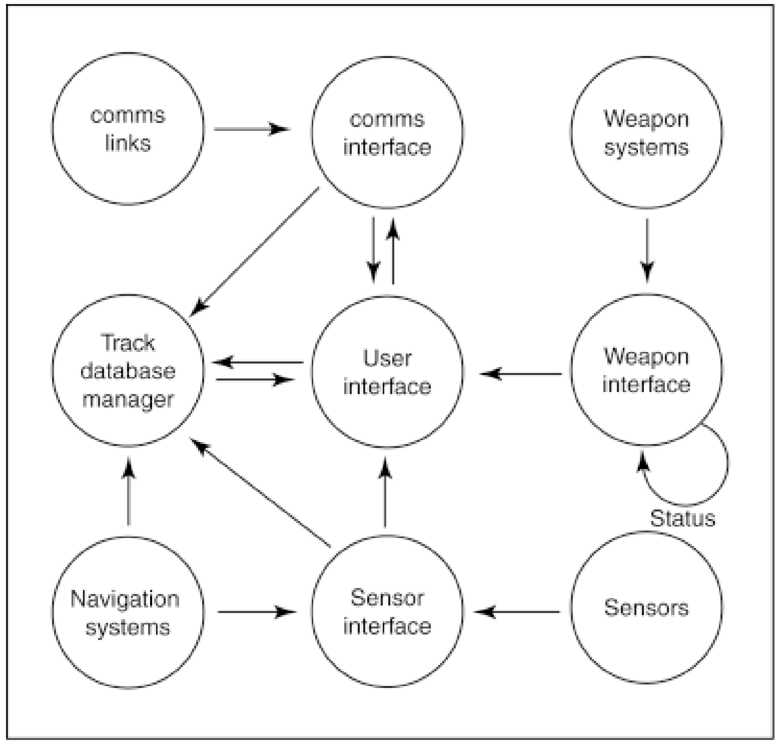

Figure 3. Generic C3I Interactions Among Systems.

Software engineering faculty at NPS were able to demonstrate that many of these difficulties could be effectively addressed by prototyping and computer-aided design techniques. The feasibility study led to the development of a generic C^3I workstation using the Computer Aided Prototyping System (CAPS), a rapid prototyping environment developed by the NPS Software Engineering faculty for the National Science Foundation. The resulting C^3I prototype contained characteristics typical of embedded software, including distributed processing, precise real-time constraints, predefined hardware interfaces, and communication links to workstations on other platforms. The prototype slice included both a generic C^3I station and its interacting external systems (Figure 3). To better simulate the proposed behavior of the C^3I workstation and the external systems, we defined the C^3I prototype as a closed system. The experiment showed, for the first time, that it was feasible to integrate C^3I systems through the use of software. Since that time, this practice has been widely accepted and utilized by industry. The experiment also

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SOFTWARE ENGINEERING PROGRAM, *continued from page 46*

demonstrated the feasibility of using computer-aided prototyping for practical, real-time applications. The availability of the computer-aided prototyping tools helped users to better visualize and understand the effects of real-time constraints and enable them to fine-tune the systems. Details of this project were reported in the technical journal *IEEE Software* in 1992[8].

As part of the Next Generation Computer Effort, the NPS team was tasked by the Naval Sea Systems Command (NAVSEA) to determine the feasibility of developing combat directive systems and tactical displays on general-purpose workstations. The prototyping effort again demonstrated that the use of computer-aided program generation could be used to build such displays both effectively and economically.

In order to transfer the technology to DoD and the soft-

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SOFTWARE ENGINEERING RESEARCH CENTER, *continued from page 13*

- Engineering automation for the design, generation, evolution, reuse and re-engineering of software
- Software reliability models and metrics
- Distributed, network-based systems
- Automated decision support for software management and risk assessment
- Automated generation of wrappers for interoperability and security support of component-based systems
- Architectural framework for integrating system components
- Formal risk assessment model for software project management
- Re-engineering of large DoD legacy systems
- Automated test and debugging

The Center is sponsored in part by research grants from the following agencies:

- Air Force Office of Scientific Research (AFOSR) – Automation of software engineering processes and procedures
- Army Research Office (ARO) – Automated engineering of reliable software
- Defense Advanced Research Projects Agency (DARPA) – Dynamic

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Participation of some of the best NPS researchers has made the Software Engineering Program successful. The program grew from the fruition of collaboration. Intellectual and organizational collaboration established the Software Engineering Automation Center.

The Institute for Joint Warfare Analysis under the direction of **Professor Gordon Schacher** initiated support for applying software engineering research to large DoD software problems. **Associate Professor Bela Ramesh** (formerly with the Department of Systems Management) and Luqi advanced research on software requirements. **Professor Norm Schneidewind**, Information Systems Academic Group, developed methods to assess and measure software reliability. **Professor Dan Dolk**, also of the Information Systems Academic Group, contributed to decision support. **Assistant Professor Mark Nissen**, Department of Systems Management, applied system management techniques to software project management. **Professors Carl Jones** and **Dan Boger**, Information Systems Academic Group, addressed the means to measure the effectiveness of software technology. **Associate Professor Bill Kemple**, Command, Control, Communications, Computers and Intelligence (C4I) Academic Group, provided outstanding domain knowledge on software interoperability. **Associate Professor Bert Lundy** and **Assistant Professor Geoffrey Xie**, Department of Computer Science, advanced software technology for networks. A world-class researcher, **Professor Valdis Berzins**, Department of Computer Science, invented the field of software merging and slicing to automate parts of software maintenance and developed most new software engineering courses to apply and transfer the new results. **Associate Professor Man-Tak Shing** established the means to deliver the Software Engineering Program to a large DoD audience via distance learning. **Associate Professor John Osmundson's** (C4I Academic Group) software management skill, **Assistant Professor Brett Michael's** (Department of Computer Science) expertise in software security, and many others including **Associate Professors Wei Kang** and **Craig Rasmussen**, Department of Mathematics, Visiting Professor Richard Riehle, **LCDR Chris Eagle, USN**, and **Professors Neil Rowe** and **Robert McGhee**, Department of Computer Science, greatly extended the scope of software engineering courses and student thesis research.

SOFTWARE ENGINEERING PROGRAM, *continued from page 47*

ware industry at large, CAPS was distributed to the public domain under the Ada Technology Insertion Program (ATIP). CAPS, besides being a useful tool for the hard real-time system developers, has also proven to be very useful for the program managers. They can use CAPS to ensure that acquisition efforts stay on track and to test the products delivered by contractors. CAPS enables one to validate system requirements via prototyping demonstration, significantly assuring that the systems developed by DoD contractors actually meet the sponsors' needs. The validated high-level designs resulting from these prototypes can be used to formulate contracts and subcontracts for subsystems that ultimately avoid many of the system integration problems. Additional problems can be detected and resolved earlier by testing the interactions between the already delivered subsystems and the prototypes of subsystems not yet completed.

Since any and all successful software inevitably must undergo changes during its lifetime, both a hypergraph model and the necessary software tools were developed to partially automate the process of software evolution. These tools provide the decision support and "electronic" file cabinets to assist project managers to track and manage changes.

While the NPS researchers were successful in advancing the software technology during this period, they were also frustrated by the gap between the state-of-the-art and the state-of-the-practice in the software community. Hence, in the mid-nineties, their focus shifted to a definition and creation of a software engineering curriculum and over twenty new courses were developed to better address the changes rapidly occurring in the field.

Faculty and students are currently working on a wide range of current, real-world software engineering problems relevant to the warfighting environment, including weapon software safety, missile control and real-time retargeting control software, requirements definition for the carrier integrated digital environment (CIDE), conceptual DoD Modeling and Simulation, system integration and interoperability of joint

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SOFTWARE ENGINEERING RESEARCH CENTER, *continued from page 47*

assembly for system adaptability, dependability, and assurance

- Defense Modeling and Simulations Office (DMSO) – Assessment of DMSO conceptual models of the mission space
- Joint Battle Center (JBC) – XML technology assessment in support of C4I systems
- Naval Air Systems Command (NAVAIR) – Assessment of communications and decision support system requirements for the next generation aircraft carrier
- Naval Sea Systems Command (NAVSEA) – Weapons Software Safety Program
- Naval Research Laboratory (NRL) – Real-time systems
- Institute for Joint Warfare Analysis (IJWA) – Interoperability and requirements definition for network centric C4I systems
- National Science Foundation (NSF) - Language support for adaptable software architectures
- Office of Naval Research (ONR) – Interoperability of real-time systems
- Space and Naval Warfare Center (SPAWAR) - Distance learning programs leading to the award of advanced academic degrees

Hardware Laboratory

The hardware laboratory contains a variety of desktop PCs and workstations, running a mix of Microsoft©, Sun© Solaris™ UNIX, and Linux operating systems. Windows NT™, Linux, and Solaris systems are well instrumented to operate as a teaching tool. The equipment allows the student to experience hands-on knowledge of performance characteristics and conduct experimental research. These activities reinforce concepts taught in the classroom. A suite of video-teleconferencing equipment (Polycom MP512) and several sets of desktop video teleconferencing equipment (Intel ProShare) are available for use by faculty and students conducting software engineering related activities. New equipment and software are added regularly to maintain the lab's currency. This highly capable lab ensures the delivery of high caliber distance learning instruction and interactive discussions.

The lab hosts the Computer Aided Prototyping System (CAPS) developed and refined over the last 15 years. A research version is available for students to use. The newest version, Distributed CAPS (D-CAPS) is under development. This effort offers students an outstanding opportunity to join a competitive research and development project.

SOFTWARE ENGINEERING PROGRAM, *continued from page 48*

services systems, data modeling and standardization for the Meteorology/Oceanography (METOC) systems, and risk assessments applicable to evolutionary software development.

One of the major problems facing DoD today is the integration and interoperability in the joint services environment. DoD software systems can be categorized into two general categories — Management Information Systems (MIS) and War Fighter/Embedded Real-Time Systems with a wide-range of hybrid and component systems between them (Figure 4).

These systems are managed by different organizations using different policy guidance, but they show common characteristics. Each system may be either distributed or heterogeneous and network-based, consisting of sets of subsystems, running on different platforms that work together via multiple communication links and protocols. When integrating these systems together to support joint operations, the artificial boundary between MIS and embedded systems results in subtle and complex integration and interoperability problems.

Many DoD information systems are COTS/GOTS based (commercial/government off-the-shelf – which may include “legacy systems” of varying age and size). While using individual COTS/GOTS components saves DoD money, it shifts many of the problems and costs from software development to software integration, interoperability and maintainability. It is commonly (and incorrectly) thought that interoperability problems are caused by incompatible interface and data formats, which can be fixed “easily” through the use of interface converters and data formatters. However, the real challenges in fixing interoperability problems are: 1)Incompatible data interpretations, 2) Inconsistent assumptions, 3) Requirements extensions triggered by global integration issues, and 4) Timely data communication between components.

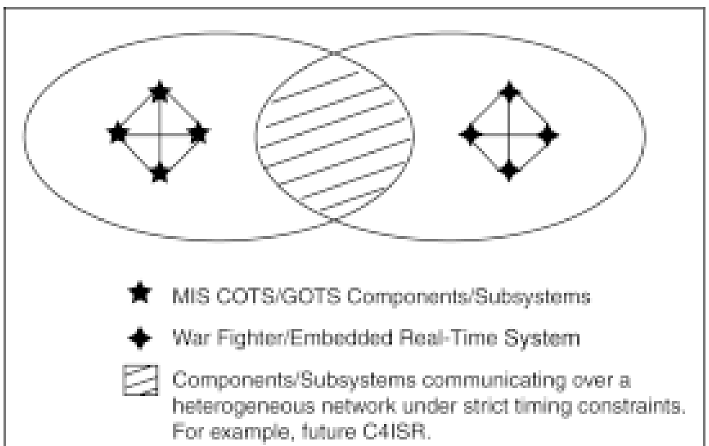

Figure 4. DoD Computer-based Systems.

Many DoD information systems, especially Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems, often operate under tight timing constraints. Builders of COTS/GOTS based systems have no control over the network upon which the components communicate. They have to work with available infrastructure and need tools and methods to assist them in making correct design decisions in order to integrate COTS/GOTS components into a distributed network based system.

Similar integration and interoperability problems are found in the commercial sector, and real-time issues are a source of growing concern. For example, just-in-time manufacturing, on-demand accounting, and factory automation frequently involve challenging timing requirements. Although software engineers have more control over interfaces and data compatibility between individual components of warfighter systems, they often encounter critical similar data communication problems when they need to connect these components via heterogeneous networks.

Many of these interoperability and integration problems have been solved using prototyping and a “wrapper and glue” technology. The NPS approach is based upon a distributed architecture where components collaborate via message passing over heterogeneous networks. A generic interface is used that allows system designers to specify communication and operating requirements between components as parameters, based on properties of COTS/GOTS components. A separate parameterized model of network characteristics constrains the concrete “glue” software generated for each node. The model enables partial specification of requirements by the system designers and allows them to explore design alternatives and to determine missing parameters via rapid prototyping.

Early work by NPS researchers in evolutionary software development has exposed a major weakness in software risk assessment. Current software risk assessment methods are typically based on the same assumptions as Royce’s Waterfall software life cycle model, and work properly only if the projects have a fixed set of requirements and design. It was found that such is rarely the case in large software development projects. The use of prototypes introduces an additional

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SOFTWARE ENGINEERING PROGRAM, *continued from page 49*

challenge for the project planner due to the uncertain number of prototyping cycles necessary prior to starting construction of the product and the uncertain amount of complexity to be covered at each cycle. Many existing project management and estimation techniques are based on linear layouts of activities. Critical Path Method (CPM) and Program Evaluation and Review Techniques (PERT) are not well suited to deal with cycles because they are based on directed acyclic graphs.

The evolutionary prototyping software process was improved by introducing additional vertices in the graph model of software evolution to represent the risk assessment steps (Figure 5). A risk assessment step can be automatically done after the completion of the specifications. Computer-aided tools, like CAPS, provide the automation needed to derive the complexity of the product from the specifications. This derivation can be combined with personnel and organizational information and with the metrics of requirements collected from the baselines to produce the risk assessment. The requirements analysis step integrates these measures with issues in the issue analysis steps. This new approach won praise from Drs. Boehm and Putnam, the pioneers in software assessment research[9].

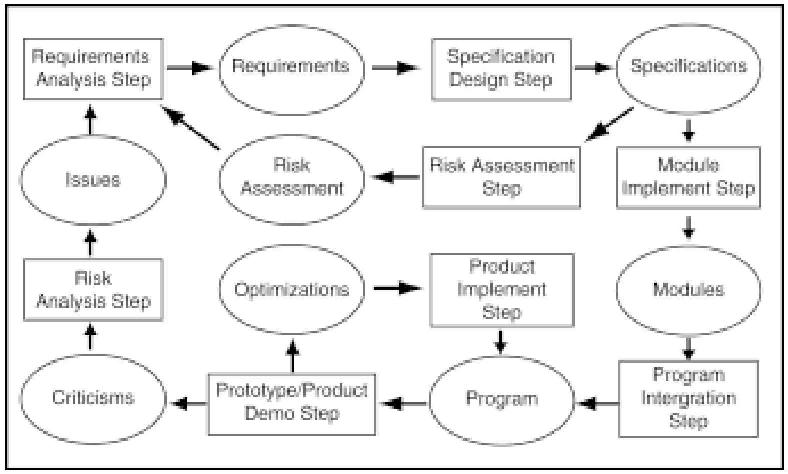

Figure 5. The improved evolutionary prototyping software process.

Technology Transfer

Being the leader in DoD software engineering also requires spearheading the transfer of technological advancements from both academia and industry to DoD. To this end, the NPS Software Engineering Automation Center has conducted a series of workshops aimed at increasing the impact of formal methods on software development. These workshops brought together government research sponsors and researchers from the academic, industrial, and DoD operational communities to address ways to bring theory into practice. These workshops, now known as the Monterey Workshop series, have resulted in many new directions for DoD software engineering research and have fostered collaborations between DoD and academic researchers that would not otherwise have been possible. Mike Reed, an Oxford University Queen's Award Winner, has hailed the Monterey Workshop series as the "best workshop" in software engineering.

The NPS Software Engineering Automation Center is thus key to a multi-discipline activity, bringing together faculty and students from Information Technology Management, Operations Research, Mathematics, Electrical and Computer

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LCDR George Greenway, USN, (September 1999) with Associate Professor Man-Tak Shing of the Department of Computer Science came up with an idea for an Automated Communications Intercept, Direction Finding, and Analysis System (ACIDS). The project was based upon the use of commercial-off-the-shelf (COTS) components. LCDR Greenway came to NPS with his Signals/Information Warfare expertise and understood that the fleet lacked capable and effective signals intercept equipment that was small scale (transportable) and inexpensive. He understood what the SigInt fleet users needed and proceeded, under the guidance of Professor Shing, to develop a COTS solution to meet the needs. With support from the Office of Naval Research's Naval Fleet Force Technology Innovation Program, LCDR Greenway built a prototype and tested it with two groups of fleet users - signals intercept operators and fleet users at USNAVCENT in Bahrain. LCDR Greenway's efforts resulted in the blue print (requirements and design) of a COTS-based, effective signals interceptor that is small scale (transportable) and inexpensive. Subsequently, LCDR Greenway's initial prototype has been further developed by the Navy into EARS (Environmental, Analysis and Receiver System) and is being manufactured in larger numbers for service use. This is another good example of how innovative ideas at NPS have resulted in products of high value to the Fleet. LCDR Greenway's project also exemplifies the unique contributions of NPS' Software Engineering students to DoD.

SPACECRAFT RESEARCH AND DESIGN CENTER, *continued from page 17*

developed vibration suppression techniques of spacecraft structures using H-infinity optimized wave absorbing control. Major Mostafa Elshafei, Eqyptian Air Force (Ph.D. Aeronautical Engineering, September 1996) and Agrawal developed improved techniques for shape control of composite material plates using piezoelectric actuators. The application of this work is for the shape control of spacecraft antennae to correct surface errors introduced by manufacturing, in-orbit thermal distortion, and moisture. LT Kirk E. Treanor, USN (Aeronautical and Astronautical Engineer, June 1996) and Agrawal developed techniques for optimal placement of piezoceramic actuators for shape control of beam structures. Song, LT Brian L. Kelly, USN (M.S. Astronautical Engineering, December 1998) and Agrawal have developed active position control techniques for shape memory alloy wire actuated composite beam. Song, LT John Vlattas, USN, (M.S. Astronautical Engineering, June 1998), LT Scott E. Johnson, USN, (M.S. Astronautical Engineering, June 1998) and Agrawal have developed control techniques for active vibration control of a space truss using PZT stack actuator. Major Steven G. Edwards, USAF (Ph.D. Aeronautical and Astronautical Engineering, September 1999), Agrawal, Professor Phan of Princeton, and Longman have developed a novel technique, the Adaptive Clear Box, for isolating a payload from rapidly varying disturbance vibrations. Edwards for his Ph. D. dissertation implemented the Multiple Error LMS and Clear Box Algorithms on the UQP and developed several enhancements. Working with Professor Agrawal, H. J. Chen for his Ph.D. dissertation work at Columbia University, implemented a Frequency Domain Clear Box Algorithm on the UQP with two enhancements. First, a phase Cancellation Repetitive Control Algorithm was added to the process of generating feed forward cancellation signal. Second, when the situation of limited control authority was encountered, quadratic programming algorithm was introduced which allows partial control of some disturbance frequencies.

FLTSATCOM Laboratory

The Fleet Satellite Communications (FLTSATCOM) Laboratory, as shown in Figure 9, consists of a qualification model of the Navy communications satellite, FLTSATCOM, and the ground Telemetry, Tracking and Command (TT&C) system. Development of this laboratory was started in 1991. LT Kevin Ham, USN (M.S. Astronautical Engineering, December 2000) working on his thesis with the support of the Naval Satellite Operational (NAVSOC) engineers has made the system operational. NAVSOC uses this laboratory to test their telemetry and command software before using them on operational FLTSATCOM satellites and plan to use it in the future for on-orbit anomaly resolution. Students are using this laboratory in a course to get hands-on experience on the functional testing of a satellite. The laboratory also has a FLTSATCOM simulator, which provides a graphical display of the spacecraft's attitude and rotational motion in response to commands similar to the commands required for flight FLTSATCOM spacecraft. Three M.S. theses have been

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Figure 9. FLTSATCOM Laboratory.

SPACECRAFT RESEARCH AND DESIGN CENTER, *continued from page 51*

completed from the research conducted in this laboratory.

Spacecraft Design Laboratory

The Spacecraft Design Laboratory houses computer-aided design tools for spacecraft design and a spacecraft design library. Students use this laboratory extensively for collaborative spacecraft design classes. The development of this laboratory was started in 1997. Currently, the computational laboratory consists of ten Pentium Pro based PCs, two sun workstations, one CAD plotter, one laser printer, one color printer, and one color scanner connected to a local network and the NPS network. This laboratory has significant support from Computational Technologies, Inc. (CTEK) and Aerospace Corporation. CTEK has installed GENSAT, a general-purpose software application for collaborative spacecraft design. It integrates several subsystem design software packages, such as STK, NASTRAN, IDEAS, and Matlab/ Simulink. Aerospace Corporation has installed the software they developed for their Concept Design Center. This software is based on the Concurrent Engineering Methodology, which is a collection of techniques, lessons learned, rules of thumb, algorithms, and relationship that have been developed for conceptual space system design. Using these unique design tools, ten students can do collaborative spacecraft design. The Spacecraft Design Library contains information on the current technologies used in spacecraft design. Material in the library covers mission planning, electric power, thermal control, structural design, guidance and attitude control, TT&C, test, and available launch systems.

The Spacecraft Design Laboratory is a unique laboratory among academic institutions for spacecraft design. Students use the laboratory for the Spacecraft Design II Course (AA 4871), which is highly recognized by DoD organizations and industry for the quality of work produced by the students on a team project to design a spacecraft system to the requirements of the sponsor. Students have received the AIAA Graduate Team Space Design Competition Award several times and twenty spacecraft design projects have been completed. Examples of some of these projects are: High Latitude Communications Satellites, Low Earth Orbit Communications Satellites, and High Temperature Superconducting Infrared Imaging Satellite, Topaz II Nuclear Powered SAR Satellite, Tomgraphic Satellite System, Spectral Sensing Space System, Multiple Asteroid Explorer, MEO UHF Satellite Constellation, Space Based Radar Spacecraft, and Mithra Relay Mirror Spacecraft.

Future Development

In December 2000, the National Reconnaissance Office (NRO) under the Director's Innovative Initiative Program selected Agrawal's proposal for funding of the Bifocal Relay Mirror Technology Development Project. The effort will consist of development of new technologies in target acquisition, tracking and pointing, beam control optics and integrated beam/spacecraft control. This effort will require an upgrade of the Three-Axis-Attitude Control Simulator by adding fast steering mirrors and lasers. Some new sensors will

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Figure 10. Spacecraft Design Laboratory.

SPACECRAFT RESEARCH AND DESIGN CENTER, *continued from page 52*

also be added. The effort will include integrating spacecraft attitude control, fast steering mirror control, and vibration isolation. A new test bed to demonstrate end-to-end relay mirror beam pointing, tracking and control will also be designed. The Air Force Research Laboratory will provide expertise on optics.

Assistant Professor Michael Spencer joined NPS in September 2000. He is developing a fifth laboratory in the center, the Satellite Servicing Laboratory. This laboratory will be used to conduct research into the development and validation of autonomous control algorithms as well as various hardware elements necessary for autonomous rendezvous and docking, space manipulator control, and satellite servicing operations.

On-orbit docking and servicing of spacecraft has been an area of research and development since the early manned space missions. Space vehicle docking was first accomplished during the Gemini program in 1966 and has progressed to the current Shuttle-Mir and Shuttle-Space Station systems. Robotic operations in space have also been developed with the Shuttle Remote Manipulator System (SRMS); however, these systems were developed for large space vehicles (100,000s kg) and require a man-in-the-loop.

Currently unmanned space systems are being designed smaller and built faster to provide a more responsive capability for payload customers. The Air Force, NRO, and NASA have several space missions in development, using several small spacecraft instead of single large vehicles. Developing the capability to refuel and service these smaller spacecraft on-orbit can greatly extend the usefulness and lifetime of the mission. Exploitation of robotic techniques can provide the needed capabilities for fully autonomous on-orbit fueling, modification and simple assembly in space.

The development of smaller, more versatile spacecraft has added a new focus for research into autonomous space robots and space manipulator systems capable of interfacing with vehicles in the 100s kg scale. Future space robotic systems must possess capabilities beyond those of the SRMS, which operated at low speeds as a single robotic arm linked to its massive Shuttle base. The next generation of space robots and space manipulators will also involve smaller servicing vehicles similar in size to the receiver vehicles. When the manipulator "base" spacecraft is comparable in mass and moments of inertia to the manipulator-plus-payload, the reactive base motions will be significant, complex and highly nonlinear. The robotic methods and systems used in the Shuttle and SRMS are no longer sufficient or applicable to the new small spacecraft robotic servicing tasks of the future. Reliable space-based manipulator operations therefore require new control strategies that consider the uncertain external environment of space while also accounting for the complex spacecraft-manipulator dynamic coupling.

The proposed effort is to design, develop and operate a servicing spacecraft simulator to conduct research into autonomous rendezvous, docking and control of a small manipulator vehicle. The servicing spacecraft simulator will float on a granite table using air pads to provide a frictionless 2-D simulation of the on-orbit operations. A schematic of the proposed system is shown in Figure 11. The servicing spacecraft simulator will move freely about the table surface to perform tracking, docking and manipulator operations. The simulator will use air thrusters and a momentum wheel to translate and rotate about the workspace. The real-time control will be developed and implemented using a dSpace control system. The servicing simulator is also to be a test-bed for various small spacecraft docking, refueling and servicing hardware elements which can be integrated into the top of the simulator and tested against appropriate target systems. Docking experiments will be conducted with a free-floating target satellite.

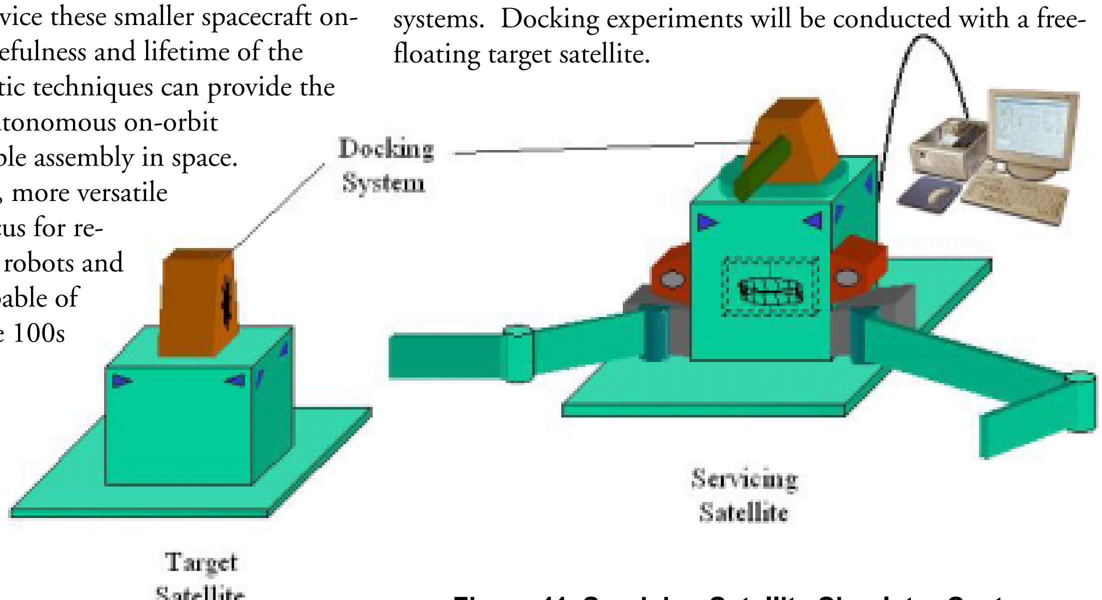


Figure 11. Servicing Satellite Simulator System.

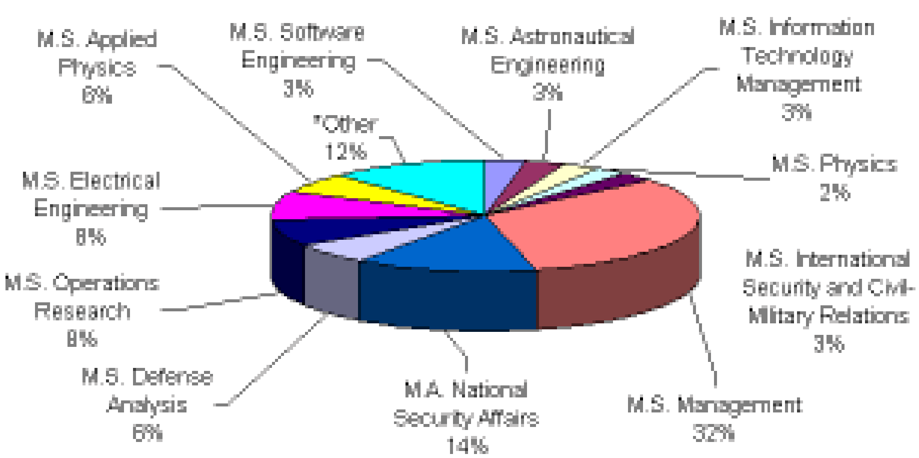
SOFTWARE ENGINEERING PROGRAM, *continued from page 50*

Engineering, Computer Science, and Command, Control, Communications, Computers and Intelligence. It continues to develop distance learning capabilities to bring the classroom experience to students around the globe, and to encourage research collaborations and technology transfer to the DoD.

"The linchpin of progress from vision to experimentation to reality is joint training and education – because these are the keys to intellectual change. Without intellectual change, there is no change in doctrine, organizations, or leaders."[10] The continued success of the NPS software engineering program is dependent upon the continued support of the DoD, the Department of the Navy, and Combatant Commanders. The DoD can optimize its return on the educational investment by employing the graduates where they can effectively create the warfighting capabilities of the future.

1 "Joint Vision 2020, America's Military: Preparing for Tomorrow," June 2000, pg. 10.
2 W. Gibbs, "Software's Chronic Crisis," *Scientific American*, Sept. 1994, pp. 86-95.
3 R. Glass, "An Assessment of Systems and Software Engineering Scholars and Institutions," *Journal of Systems and Software*, October 1994.
4 L. Bernstein, "Forward: Importance of Software Prototyping," *Journal of Systems Integration – Special Issue on Computer Aided Prototyping* 6, (1996), 9-14.
5 D. Rusin, Luqi and M. Scanlon, "SIDS Wireless Acoustic Monitor (SWAM)," *Proceedings of the 21st International Conference on Lung Sounds*, Chester, England, 4-5 September 1996.
6 V. Berzins, M. Shing, Luqi, M. Saluto and J. Williams, "Object-Oriented Modular Architecture for Ground Combat Simulation," *Proceedings of the 2000 Command and Control Research and Technology Symposium*, Naval Postgraduate School, Monterey, CA, June 26-28, 2000.
7 Luqi and W. Royce, "Status Report: Computer-Aided Prototyping," *IEEE Software* 9(6), Nov. 1992, pp. 77-81.
8 Luqi, "Computer-Aided Prototyping for a Command-and-Control System using CAPS," *IEEE Software*, January 1992, pp. 56-67.
9 J.C. Nogueira, A F*ormal Model for Risk Assessment in Software Projects*, doctoral dissertation, Naval Postgraduate School, Monterey, CA, September 2000.
10 "Joint Vision 2020, America's Military: Preparing for Tomorrow," June 2000, pg. 35.

ACADEMIC DEGREES-DECEMBER 2000



*Ph.D. Computer Science (1); Ph.D. Meteorology (2); Ph.D. Physics (1); Ph.D. Operations Research (1); Electrical Engineer (1); Mechanical Engineer (2); M.S. Aeronautical Engineering (2); M.S. Computer Science (3); M.S. Engineering Acoustics (1); M.S. Material Science (1); M.S. Mechanical Engineering (1); M.S. Modeling, Virtual Environments and Simulation (1); M.S. Systems Technology (1); M.S. Meteorology and Physical Oceanography (1)

Although the curricula at NPS are tailored to address defense requirements, they are developed within the framework of classical academic degrees, meeting the highest academic standards. Each curriculum leads to a master's degree; however, additional study can lead to either an engineer's degree or the doctor's degree. There were 165 degrees conferred at the December 2000 graduation. The thesis is the capstone achievement of the student's academic endeavor at NPS. Thesis topics address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain long-term superiority of the Navy/DoD. A thesis is a degree requirement for most NPS curricula. Thesis abstracts of the December 2000 graduates can be found on line at http://web.nps.navy.mil/~code09/.

CONFERENCE CALENDAR

UPCOMING CONFERENCES/SHORT COURSES/MEETINGS AT NPS

Date	Title	Sponsor
29 January-1 February 2001	Military Sensing Symposia (MSS) Specialty Group Meeting on Missile Defense Sensors, Environments and Algorithms	U.S. Army Communications Electronics Command
29 January-2 February 2001	Unmanned Aerial Vehicles (UAVs) Payload and Links Course	Association of Old Crows
5-6 March 2001	The Factors Affecting the Reception of Radio Signals	Naval Security Group, Army Intelligence and Security Command (in cooperation with the National Science Foundation and the Federal Communications Commission)
19-23 March 2001	17th Annual Review of Progress in Applied Computational Electromagnetics	Naval Postgraduate School and the Applied Computational Electromagnetics Society
27-29 March 2001	12th Annual U.S. Army Tank-Automotive & Armaments Survivability Symposium	U.S. Army Tank and Automotive Command
23-27 April 2001	Technology Review and Update	Naval Postgraduate School
23 April - 11 May 2001	Revolution in Battlespace Technology	Naval Postgraduate School
30 April-3 May 2001	Joint Electronic Warfare Conference	U.S. Army Research Laboratory
15-17 May 2001	Target Tracking and Sensor Fusion Workshop	Naval Postgraduate School, University of New Orleans, Georgia Tech Research Institute
22-23 June 2001	36th Annual Colonel Allyn D. Burke Memorial Dental Symposium	Colonel Allyn D. Burke Memorial Dental Study Club
16-20 July 2001	Classified Advanced Technology Update	Naval Postgraduate School
23-25 January 2002	AIAA Strategic and Tactical Missile Systems Conference	American Institute of Aeronautics and Astronautics
10-15 March 2002	Hardened Electronics and Radiation Technology Conference	Defense Threat Reduction Agency, Sandia National Laboratories, U.S. Army Space & Missile Defense Command, Navy Strategic Systems Program Office

NPS has excellent facilities for hosting conferences, workshops, symposia, and meetings. The wide range of facilities can accommodate both small and large groups. Additional rooms are available for smaller functions or breakout sessions. Conferences classified through SECRET can be accommodated on the NPS campus. Sensitive Compartmented Information Facility (SCIF) facilities exist and may be available for small groups on a more restricted basis. For more information, contact the NPS Conference Coordinator, Eileen Hamilton, at 831-656-2426 or by e-mail, eehamilt@nps.navy.mil.

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